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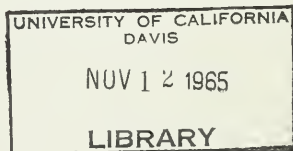
NORTH COASTAL AREA INVESTIGATION

Appendix E

ENGINEERING GEOLOGY

Volume I: Upper Eel River Development

August 1965



HUGO FISHER
Administrator
The Resources Agency

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Director
Department of Water Resources

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THE RESOURCES AGENCY
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BULLETIN No. 136

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Appendix E
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FOREWORD

The report on the North Coastal Area Investigation consists of Bulletin No. 136, four separately bound appendixes to the bulletin, and three separately bound office reports. The appendixes cover the subjects of watershed management, recreation, fish and wildlife, and engineering geology. The office reports cover alternative plans for development, designs and cost estimates, and hydrology. The land and water use and economics data utilized in the investigation are published in the Bulletin No. 94 series on land and water use in the various hydrographic units, and in Bulletin No. 142-1 on water resources and future water requirements in the North Coastal Hydrographic Area.

Bulletin No. 136 provides a general description and summary of the North Coastal Area Investigation. It outlines the objectives, activities, and conclusions of the investigation and describes the plans which have been formulated. The technical record of the investigation is summarized in the appendixes and office reports. A brief discussion of the investigation is presented in Chapter I of this appendix.

This appendix covers all of the individual geologic investigations conducted during the North Coastal Area Investigation. The coverage devoted to individual damsites and tunnel alignments varies with the level of work performed and the importance of the feature in the plans for development. The discussions for major damsites include detailed descriptions of the foundation conditions and available construction materials. Discussions of major tunnel alignments include estimates of tunneling conditions and descriptions of anticipated problem areas.

This appendix is divided into two volumes. Volume I contains Chapters I to IV covering the possible projects involved in the Upper Eel River Development, including the Middle Fork Eel River Projects, the Glenn Reservoir Projects, and the Upper Eel River Projects. Volume II contains Chapters V to X covering the other projects studied in the North Coastal area, including the Trinity, South Fork Trinity, Mad, Van Duzen, Lower Eel, and Klamath River drainage areas.

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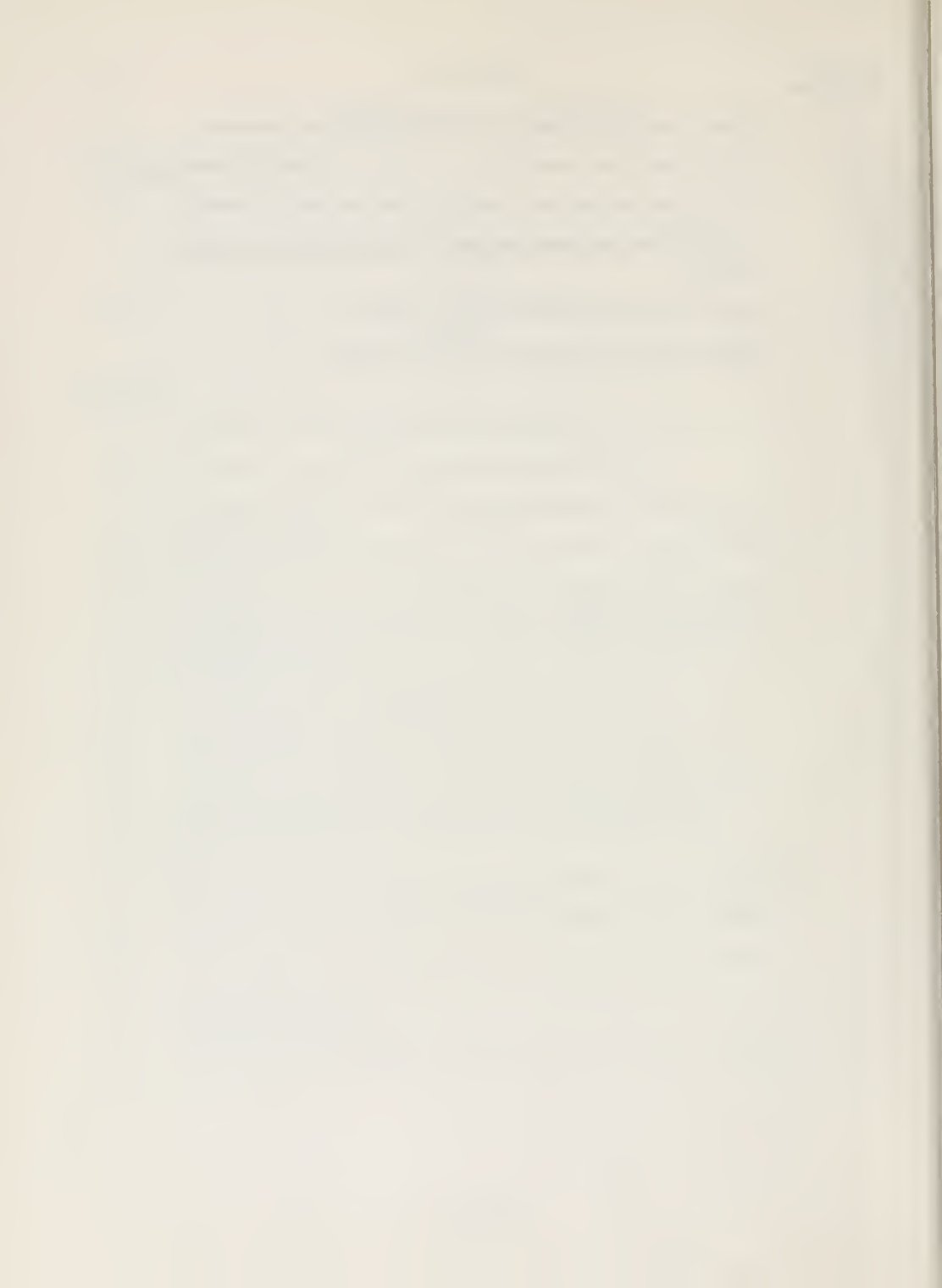
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July 27, 1965

Honorable Edmund G. Brown, Governor
and Members of the Legislature
of the State of California

Gentlemen:

I am pleased to transmit herewith an appendix to Bulletin No. 136, "North Coastal Area Investigation", entitled Appendix E, "Engineering Geology".

Most engineering decisions on tunneling conditions, suitability of damsites, and availability of construction materials depend heavily on the accumulation and interpretation of geologic information. This appendix summarizes all of the geologic information which has been accumulated during the Department's 7-year reconnaissance investigation of the North Coastal area.

As the planning level for selected projects moves up to the feasibility stage, more detailed geologic information will be required. The information summarized in this appendix will be the foundation for the more detailed study.

Sincerely yours,

A handwritten signature in dark ink, appearing to read "William E. Swann". The signature is fluid and cursive, with a long horizontal stroke extending to the right.

Director

Attachment



State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

EDMUND G. BROWN, Governor, State of California
HUGO FISHER, Administrator, The Resources Agency
WILLIAM E. WARNE, Director, Department of Water Resources
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NORTHERN BRANCH

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CHAPTER I. INTRODUCTION

There is growing recognition that the key to sustaining California's growth will be timely and substantial development of new water supplies in the North Coastal area. At the present time, the potential wealth of this resource has scarcely been tapped. Increasing statewide water demands, however, are bringing the threshold of extensive development nearer. The need is manifest for a comprehensive planning framework to ensure that this development is efficient and orderly. The results of the North Coastal Area Investigation are conclusions and plans for development which comprise that framework.

North Coastal Area Investigation

With the publication of Bulletin No. 136, and related appendixes and office reports, the Department of Water Resources concludes the 7-year reconnaissance phase of the continuing North Coastal Area Investigation.

Need

The need for the North Coastal Area Investigation arose from the conclusions of Bulletin No. 3, "The California Water Plan". That document concluded that there is enough water in California to satisfy the State's long-range water requirements if the available resources are wisely controlled, conserved, and distributed. While demonstrating that the State does have sufficient water available, Bulletin No. 3 also outlined the way to effectively utilize the resource.

With the recognition that many of the State's future water requirements would be met from surplus North Coastal supplies, it was apparent that a planning framework was needed to assure that each new project in this area represented a logical and orderly increment in long-range development. The basic need was to translate the broad planning concepts reported in Bulletin No. 3 into a workable plan of staged project development. In providing a plan for the North Coastal area, the Department can assure the people of the

State that each proposed new project in the area, irrespective of the constructing agency, is a logical and economical step in meeting California's statewide water demands.

An additional need for this investigation stems from the Department's role as the constructor and operator of a statewide water utility. The Department is presently constructing the initial facilities of the State Water Project, a system of works which, when fully operative, will conserve, transport, and deliver to public agencies throughout the State approximately 4 million acre-feet annually of new water supplies. Most of this water will be diverted from the Sacramento-San Joaquin Delta. In recognition that the supplies of water in the Delta will be gradually diminished as development takes place in the tributary areas, provisions were made in the Burns-Porter Act for financing construction of additional conservation facilities needed to maintain the minimum water yield of the State Water Project. With the need to construct the initial additional facility appearing on the horizon, it has been imperative that the State work diligently towards selecting a North Coastal project to satisfy the requirement.

Scope

The major purpose of an area-wide plan of water development in the North Coastal area is to develop presently uncontrolled runoff for meeting requirements in local areas and for export of surplus water to water-deficient areas within the State. Within the framework of a comprehensive water development plan it is possible to consider many associated and interrelated aspects of water control, distribution, and use. In this investigation the following additional purposes were considered for inclusion as multiple-purpose uses of the conservation and conveyance facilities: fisheries enhancement, flood control, recreation, and hydroelectric power.

The areal scope of the investigation included consideration of all streams in the North Coastal area which offer apparent potential for economic development of major water conservation projects. The plan of development as presently conceived would include major projects in the Eel, Trinity, Mad, Van Duzen, Klamath, and Russian River Basins. Minor coastal drainage basins,

extending north from the Gualala River to Redwood Creek, were given cursory examination as possible locations for fisheries enhancement projects.

In addition to the above streams, which all drain westward to the coast, portions of the contiguous drainage basins on the west side of the Sacramento Valley, through which the exported water would be conveyed en route to the Sacramento-San Joaquin Delta, have also been studied. These basins include Putah, Cache, Stony, Thomas, Elder, Cottonwood, and Clear Creeks. The study of these drainage basins was directed primarily to aspects associated with the interbasin transfer of water, such as possible reregulatory storage sites and hydroelectric power features. However, substantial additional benefits, including conservation of tributary runoff, would be derived from works constructed in these basins.

The North Coastal Area Investigation has embraced many fields of study, including hydrology, geology, surveying and mapping, cost estimates and design, land and water use, watershed management, economics, recreation, fish and wildlife, and hydroelectric power. The intensity or degree of refinement for individual studies ranged from cursory analysis through high-order reconnaissance studies.

Selected Projects

Plate 1 shows the long-range development plans within the North Coastal and West Side Sacramento Valley areas which are recommended in Bulletin No. 136 for more intensive studies leading toward authorization and future construction.

Both the Upper Eel River and Trinity River Developments have two alternative diversion routes, as shown on Plate 1. These are the Glenn Reservoir and Clear Lake diversion routes for the Upper Eel River surplus waters, and the Clear Creek and West Side Conveyance System routes for the Trinity River surplus waters. Routes will be selected after further studies have been made.

Future Planning Program

Departmental planning for major water projects in the North Coastal area is being carried forward in two programs: (1) an advance planning program

for the Upper Eel River Development, and (2) continuation of the area-wide investigation of the North Coastal region. A description of these two programs follows.

Advance Planning - Upper Eel River Development. This program is an outgrowth of the authorization of the Upper Eel River Development as an additional conservation facility of the State Water Project. It will be a comprehensive planning program to provide final formulation and definition of the development. Funds for the program will come from the California Water Resources Development Bond Fund, through the "offset provisions" of the Burns-Porter Act.

The Upper Eel River Development, as described previously in this report, will consist of conservation reservoirs on the Middle Fork Eel River and associated conveyance features to deliver the conserved water supplies to local areas and to the Sacramento River Basin. Delivery will be either (1) via pumped diversion to the upper main Eel River with subsequent gravity diversion via Clear Lake, Soda Creek, Putah Creek, and Lake Berryessa to the Sacramento River, or (2) via gravity diversion to Thomas or Stony Creeks in west side Sacramento Valley with the inclusion of elements of the Glenn Reservoir Complex.

The objectives of this program are to: (1) select the conveyance route for delivering the conserved surplus water from the Middle Fork Eel River to the Sacramento River Basin; (2) identify the specific project features which will comprise the Upper Eel River Development; (3) define the capacities, sizes, costs, and other appropriate parameters of the specific project features; (4) identify local needs which could be served from the development and define the necessary appurtenant works to supply these needs; (5) determine the relationship between projected benefits and costs for the different project purposes, in order to provide a cost allocation and a project services allocation among the various purposes; and (6) provide comprehensive and specific recommendations for the subsequent programs and actions which will be necessary to design, construct, and operate this facility.

The program will be conducted in direct cooperation with the U. S. Bureau of Reclamation, the U. S. Corps of Engineers, and the U. S. Soil

Conservation Service. Close liaison will also be maintained with other federal, state, and local agencies.

North Coastal Area Investigation - Second Phase. This is the second phase of the Department's continuing planning investigation covering the entire North Coastal area. The program will be funded from the state General Fund.

Activities will be directed toward further definition of possible multiple-purpose developments in the Trinity, Mad, Van Duzen, Lower Eel, Klamath, and coastal stream basins.

The objectives of the investigation are to: (1) recommend general sequence of major, multiple-purpose projects in the North Coastal area to follow the Upper Eel River Development; (2) define specific features of the first project in this sequence in sufficient detail to enable future initiation of feasibility-level studies; (3) compare alternative projects in later-staged works; and (4) identify local projects which might be constructed for purposes of local water supply, flood control, recreation, and fisheries enhancement.

Scope of Engineering Geology Report

Most fundamental and important engineering decisions such as determination of optimum tunnel alignment, type of dam construction, and solution to other foundation problems depend heavily upon the accumulation and interpretation of geologic information. For this reason the Department has conducted extensive geologic investigations in the North Coastal area since the initiation of this program. All of the geologic information accumulated during this investigation is summarized in this report.

Geologic Investigations

Geological work accomplished by the Department prior to the North Coastal Area Investigation was limited to the reconnaissance surveys necessary for the preparation of Bulletin No. 3, "The California Water Plan". This work consisted primarily of brief memorandum reports and preliminary geological mapping of dam and reservoir sites.

Since additional and more detailed information was required for the present investigation, an intensive geological program was undertaken and has continued since 1956. This program included geologic mapping of damsites and tunnel lines, location and exploration of potential sources of construction materials, subsurface investigation of proposed dam foundations and tunnel alignments, and the preparation of office reports on the various alternative features under study.

Featured projects (see Plate 1) are discussed in detailed reports in the following chapters, while the geologic conditions of alternative or less favorable features are summarized in brief reports in tabular form. These tables appear at the end of each appropriate chapter.

Previous Geologic Reports and Investigations. During the course of the various investigations in the North Coastal area, a variety of office reports, outline reports, memorandum reports have been prepared. The most significant of these are listed in Attachment A to this report. Portions of many of these reports and maps prepared for them have been used extensively in preparing this report.

All damsites and tunnel lines studied in the North Coastal area are tabulated on Table 1, "Summary of Geological Investigations in the North Coastal Area". This table also lists the status of work performed as either: official reconnaissance, detailed reconnaissance, preliminary exploration, or pre-feasibility, and the type of report prepared. Damsites and tunnels listed in capital letters are "featured projects" for which detailed reports and/or maps are presented in the subsequent chapters.

TABLE 1
SUMMARY OF GEOLOGICAL INVESTIGATIONS
IN THE NORTH COASTAL AREA

Damsite or tunnel location	:	Stream	:	Status*
Canthook Damsite	:	Smith River	:	I
Craig Damsite	:	Smith River	:	I
Adams Damsite	:	Smith River	:	I
Hornbrook Damsite	:	Klamath River	:	I
Hamburg Damsite	:	Klamath River	:	I

* See explanation at end of table.

TABLE 1 (Cont.)

Damsite or tunnel location	:	Stream	:	Status*
Happy Camp Damsite	:	Klamath River	:	I
Red Cap Damsite	:	Klamath River	:	I
Slate Creek Damsite	:	Klamath River	:	I
Mettah Creek Damsite	:	Klamath River	:	I
Blue Creek Damsite	:	Klamath River	:	I
HUMBOLDT DAMSITE	:	Klamath River	:	II
Jackman Damsite	:	Klamath River	:	I
BURNT RANCH DAMSITE	:	Trinity River	:	IV
HELENA DAMSITE	:	Trinity River	:	IV
Lowden Damsite	:	Trinity River	:	I
Ironsides Damsite	:	Trinity River	:	I
BIG BAR DAMSITE	:	Trinity River	:	III
Horse Linto Damsite	:	Trinity River	:	I
Hoopla Damsite	:	Trinity River	:	I
Beaver Damsite	:	Trinity River	:	I
TRINITY-CLEAR CREEK TUNNEL	:	Trinity River to Clear Creek	:	II
TRINITY-COTTONWOOD TUNNEL	:	Trinity River to Cottonwood Creek	:	II
ELTAPOM DAMSITE, UPPER	:	South Fork Trinity	:	III
ELTAPOM DAMSITE, MIDDLE	:	South Fork Trinity	:	IV
Eltapom Damsite, Lower	:	South Fork Trinity	:	II
Grel Damsite	:	South Fork Trinity	:	I
Grouse Creek Damsite	:	South Fork Trinity	:	I
WAR CRY TUNNEL	:	South Trinity to Trinity	:	II
Eltapom-Big Bar Tunnel	:	South Fork Trinity	:	II
Buck Mountain Damsite	:	Van Duzen River	:	I
Dinsmores Damsite	:	Van Duzen River	:	I
Camp Damsite	:	Van Duzen River	:	I
EATON DAMSITE	:	Van Duzen River	:	III
Forks Damsite	:	Van Duzen River	:	I
LARABEE VALLEY DAMSITE	:	South Fork Van Duzen River	:	II
LARABEE VALLEY TUNNEL	:	South Fork Van Duzen to Van Duzen River	:	II
Ruth Damsite	:	Mad River	:	I
Ranger Station Damsite	:	Mad River	:	III
County Line Damsite	:	Mad River	:	I
Eight Mile Damsite	:	Mad River	:	I
ANDERSON FORD DAMSITE	:	Mad River	:	II
Butler Valley Damsite	:	Mad River	:	I
Lower Butler Valley Damsite	:	Mad River	:	IV
Blue Lake Damsite	:	Mad River	:	I
Essex Damsite	:	Mad River	:	I
ANDERSON FORD TUNNELS	:	Mad River to South Fork Trinity River	:	I
Mad River Tunnel	:	Van Duzen to Mad River	:	II
SEQUOIA DAMSITE	:	Eel River	:	IV
Island Mountain Damsite	:	Eel River	:	I
BELL SPRINGS DAMSITE	:	Eel River	:	IV
Woodman Damsite	:	Eel River	:	II

* See explanation at end of table.

TABLE 1 (Cont.)

Damsite or tunnel location	:	Stream	:	Status*
Marshall Damsite	:	Eel River	:	I
Benmore Damsite	:	Eel River	:	I
Willis Ridge Damsite	:	Upper Main Stem Eel	:	IV
ENGLISH RIDGE DAMSITE	:	Upper Main Stem Eel	:	II
Garcey Ranch Damsite	:	Upper Main Stem Eel	:	II
Presley Ranch Damsite	:	Upper Main Stem Eel	:	I
UPPER MINA DAMSITE	:	North Fork Eel River	:	I
Mina Damsite	:	North Fork Eel River	:	II
DOS RIOS DAMSITE	:	Middle Fork Eel River	:	II
Jarbow Damsite	:	Middle Fork Eel River	:	I
Etsel Damsite	:	Middle Fork Eel River	:	IV
SPENCER DAMSITE	:	Middle Fork Eel River	:	IV
UPPER ETSSEL DAMSITE	:	Middle Fork Eel River	:	II
MILL CREEK DAMSITE	:	Mill Creek Tributary to Middle Fork Eel River	:	I
FRANCISCAN DAMSITE	:	Short Creek Tributary to Fork Eel River	:	IV
Branscomb Damsite	:	South Fork Eel River	:	IV
Elkhorn Damsite	:	South Fork Eel River	:	I
EEL-GLENN TUNNEL	:	Middle Fork Eel to Glenn Reservoir	:	III
Dos Rios Tunnel	:	Middle Eel to Eel River	:	II
Sequoia Tunnel	:	Eel River to Larabee Creek	:	II
GARRET TUNNEL	:	Eel River to Clear Lake drainage	:	II
MINA TUNNEL	:	North Fork Eel to Middle Eel drainage	:	I
ELK CREEK TUNNEL	:	Middle Eel drainage to Eel River drainage	:	I
MILL CREEK TUNNEL	:	Drainage for Round Valley	:	I
SODA CREEK TUNNEL	:	Cache Creek to Putah Creek	:	III

Damsites of the Glenn Reservoir Complex

NEWVILLE DAMSITE	North Fork Stony Creek	III
PASKENTA DAMSITE	Thomes Creek	III
MILLSITE DAMSITE	Stony Creek	III
RANCHERIA DAMSITE	Stony Creek	III
CHROME DIKE DAMSITE	No Stream	III

Damsites of the West Side Feeder System

Selvester Damsite	Middle Fork Cottonwood Creek	I
Fiddlers Damsite	Middle Fork Cottonwood Creek	IV
Upper Pentacola Damsite	Dry Creek	II
Lower Pentacola Damsite	Dry Creek	II
Little Pentacola Damsite	Tributary to Dry Creek	II

* See explanation at end of table.

TABLE 1 (Cont.)

Damsite or tunnel location	:	Stream	:	Status*
Meadow Gulch Damsite	:	Meadow Gulch	:	II
Saunders Flat Damsite	:	Salt Creek	:	II
Trueblood Damsite	:	Trueblood Gulch	:	II
Long Gulch Damsite	:	Long Gulch	:	II
Wildhide Damsite	:	Wildhide Gulch	:	II
Red Bank Damsite	:	Red Bank Creek	:	II
Cold Fork Damsite	:	Cold Fork Creek	:	II
Guyre Damsite	:	Guyre Creek	:	II
McCartney Damsite	:	South Fork Cottonwood Creek	:	II
Bluedoor Damsite	:	North Fork Red Bank Creek	:	II
Schoenfield Damsite	:	Red Bank Creek	:	II
Galatin Damsite	:	Elder Creek	:	II
Cat Ridge Damsite	:	McCartney Creek	:	II
Digger Damsite	:	Digger Creek	:	II

* Damsites

- I Surficial reconnaissance level; no geological mapping; outline office report.
- II Detailed reconnaissance level; geological mapping included; memorandum report.
- III Preliminary exploration level; detailed geological mapping;
- IV Pre-feasibility level; includes subsurface exploration; comprehensive office report.

Tunnels

- I Reconnaissance geologic mapping of the tunnel area.
- II Detailed geologic mapping along a specific alignment.
- III Alignment study included subsurface drilling.

Engineering Geology of the North Coastal Area

For purposes of geologic regionalization, the North Coastal area has been subdivided into three regions, each with a characteristic assemblage of geologic and engineering properties. These regions have been designated the Klamath Mountains, the Northern Coast Ranges, and the Coast

Range Foothills. Major streams in the three regions are the Eel, Mad, Van Duzen, and Russian Rivers, and the lower reaches of the Klamath River, for the Northern Coast Ranges; the Trinity, Klamath, and Smith Rivers in the Klamath Mountains; and Clear, Cottonwood, Thomes, and Stony Creeks for the Coast Range foothills. Both preliminary and detailed geologic studies within each of these regions have disclosed many areas of uncertainty which bear directly on project formulating studies. Salient among these areas of uncertainty are weak dam foundations, poor tunneling conditions, landslide hazards, the frequent shortage of suitable dam construction materials, and seismic hazards.

The geologic conditions relating to the feasibility of the proposed features of this investigation can best be considered under six specific categories, namely: regional geology, foundation conditions, construction materials, tunneling conditions, landslide conditions, and seismicity.

Regional Geology

Klamath Mountains. The Klamath Mountains are located in the northern portion of the area studied and constitute a province of rugged mountains with the highest peaks reaching an altitude of 9,000 feet. The major streams drain in a northwesterly direction and have incised deep, narrow canyons which generally cut across the regional geologic structure.

Rock units found in the Klamath Mountains region consist predominantly of metamorphic and igneous rocks which are considerably older than units of the Northern Coast Ranges. Some of the most abundant rock types are metamorphosed volcanic and sedimentary rock including slate, phyllite, chert, schist, and greenstone. Igneous intrusive rocks range from granite to peridotite, the latter usually altered to serpentine.

The Klamath Mountains region has been subdivided into four arcuate, roughly north-south trending belts which are concave to the east. The rock units range in age from early Paleozoic to Jurassic. In general, the rocks become progressively older from west to east, and the individual belts are bounded by high-angle thrust faults. The four belts are described as follows:

1. The eastern Paleozoic belt consists of mildly metamorphosed igneous and sedimentary strata ranging in age from Ordovician to Mississippian.

2. The central metamorphic belt, which is believed to contain the oldest rocks of the region, is composed of the Abrams and Salmon formation. Principal rock types are quartz-mica schist (Abrams formation) and hornblende schist (Salmon formation).

3. The western Paleozoic and Triassic belt consists of mildly metamorphosed igneous and sedimentary rock units which have been collectively described in this report as the Chanchelulla formation.

4. The western Jurassic belt includes the mica schist, green-schist, and moderately metamorphosed sedimentary rock of the Galice formation and the South Fork Mountain schist.

Small, isolated areas within this region are underlain by sedimentary rocks of Cretaceous and Tertiary age. The poorly consolidated Tertiary material constitutes an important source of impervious fill for the proposed earthfill structures.

More regional geologic information is available on the Klamath Mountain region than anywhere else in the North Coastal area, due primarily to extensive mining activity around the turn of the century. Detailed geologic information, applicable to interpretation of dam foundation and tunneling conditions was virtually non-existent prior to the initiation of the investigation.

Northern Coast Ranges. Unlike the Klamath Mountains, the Northern Coast Ranges are geologically one of the least explored regions of California owing to a lack of mineral resources, poor accessibility, and complex geologic structure. Prior to the North Coastal Area Investigation, even the most general geologic information was unavailable for a major portion of the region.

Topographically, the province is characterized by elongated, northwest trending ridges and valleys which are controlled by the underlying geologic structure. The drainage pattern is markedly trellis, that is, the major streams are parallel to the structural grain of the area. Zones of weakness such as faults or crush zones are commonly important factors in the development of major drainage channels.

Virtually the entire region is underlain by rocks of the Franciscan formation with the Eel River Valley and several relatively small areas underlain by upper Cretaceous and Tertiary sediments. Rocks assigned to the Franciscan formation range in age from late Jurassic to late Cretaceous. The formation is probably at least 25,000 feet thick, although neither the base nor the top has been recognized.

Structurally, the Franciscan formation has an extremely disordered appearance. The rocks have been so folded, faulted, and sheared that nearly every outcrop presents some structural complexity. In addition to the complex structure, Franciscan rock units occur characteristically in discontinuous lense-shaped bodies and present at first glance a nearly chaotic mass. Major structural features, however, as well as belts of rock units or rock assemblages, are mappable and locally may be quite continuous. The prevalent orientation of Franciscan units is roughly N40W with an eastward dip. The large scale structures seem to consist of open folds cut by strike-slip faults which are nearly parallel to the San Andreas fault system. Major faults form wide zones containing blocks of competent rock in a sheared ground mass.

The Franciscan formation is generally divided into three broad belts -- the Coastal, Central, and the Eastern or Metamorphosed belt. The Coastal belt is believed to be the youngest, probably of Cretaceous age, and consists predominantly of unmetamorphosed sedimentary rock. Sandstone, shale, and conglomerate constitute about 95 percent of the entire unit.

The Central Franciscan belt consists of a great variety of rock types and is generally extremely complex structurally. In addition to sandstone, shale, conglomerate, and greenstone, the following rock types are dispersed throughout the belt though they constitute a small portion of the whole -- chert, limestone, glaucophane schist, serpentine and associated ultrabasic rock.

The metamorphosed or the Eastern belt appears to contain mildly metamorphosed equivalents of the Coastal belt. Most common rock types are slate, phyllite, quartz-mica schist, and foliated sandstone. Igneous rock is generally scarce but may attain considerable importance locally.

Landsliding on both large and small scale is widespread throughout the Northern Coast Ranges. The terrain underlain by severely folded, faulted, and crushed rock has developed a distinct type of landsliding, i.e., the earthflow type. The depth of an earthflow slide is generally quite shallow as compared to its areal extent, and resistant knobs of in-place bedrock commonly protrude through the slide debris. Large scale sliding is well illustrated along the Eel River Canyon, and is characterized by nearly continuous quasi stable grass covered slopes.

The total volume of unstable material along the slopes of the major streams in the basin is so great that it constitutes a major hazard for potential reservoir construction. Large scale sliding could reduce the storage capacity of several proposed reservoirs by as much as 10 percent as well as create the danger of embankment overtopping by landslide-caused tidal waves.

The thickest and most extensive accumulation of soil and slope-wash is found in areas underlain by crushed incompetent material such as sheared shale or zones of faulting. Near the tops of the ridges weathering has progressed to a considerable depth and thick deposits of residual soil are common. In contrast to the semi-stable side slopes, areas of residual soil are generally covered by dense vegetation.

Coast Range Foothills. The Coast Range foothills have a low to moderate topographic relief, with the highest ridges at elevations of 2,000 to 2,500 feet above sea level. The foothills are bounded on the west by the Northern Coast Ranges and on the north and east, respectively, by the Klamath Mountains and the Sacramento Valley. The region is underlain by two major geologic units, the Cretaceous bedrock series and the Tertiary-Tehama formation. The bedrock series have a relatively uniform north to northwest strike and dip to the east. Rock types include mudstone, shale, sandstone, and conglomerate listed in the order of relative abundance. The Tehama formation consists of an accumulation of continental flood plain sediments of Pliocene age. The Tehama sediments have a very gentle eastward dip and consist of poorly sorted, virtually unconsolidated silts, clay-silts, sands, and clayey gravels.

The geologic structure is readily reflected in the topographic expression of the Coast Range Foothill region and two distinct drainage patterns have developed on the two contrasting geologic units. Areas underlain by bedrock show a marked parallel alignment of drainage which is controlled by the geologic structure. Rapid erosion of the unconsolidated flat-lying Pliocene sediments has caused the development of an intricate feather-like drainage pattern.

Foundation Conditions

Klamath Mountains. Of the three geologic regions under study in the North Coastal Area Investigation, the Klamath Mountains have generally provided the most favorable dam foundation conditions. Most damsites are in hard, competent igneous and metamorphic rock and appear to be satisfactory for construction of high earth- and rockfill structures. The intensity of weathering and fracturing is highly variable; however, overall the depth of overburden is shallow and does not appear to present any unusual construction difficulties. Several sites are located on hard, extremely resistant intrusive igneous rocks and appear to be suitable for concrete gravity or possibly arch dams.

Poor foundation conditions in the region are confined to relatively narrow fault zones and altered sheared rock such as serpentine. All damsites but one (Eltapom dams site, South Fork Trinity River) in the Klamath Mountains region avoid the areas of weak rock and will be founded on excellent foundation rock.

Northern Coast Ranges. Virtually all damsites proposed within the Northern Coast Ranges are underlain by rock types of the Franciscan formation which provide some of the poorest foundation conditions within the State. The rock is generally extensively fractured, sheared, and brecciated so that areas of relatively competent rock are of limited extent and are usually surrounded by crushed, highly deformed material. Least resistant rock units such as shale and serpentine have suffered the most and have often been reduced to a clayey mass interspersed with blocks of harder rock. Faulting in the region follows the northwestern trend roughly parallel to the San Andreas fault system and is extremely widespread. All proposed sites in

the Northern Coast Ranges are located within a short distance of major fault zones and foundations of several sites are cut by faults.

The intensity of weathering in the Northern Coast Ranges is very high owing to incompetent rock, closely spaced fractures, and relatively high precipitation. The canyon slopes are usually overlain by a thick mantle of residual soil, slopewash, talus, and unstable landslide debris which will have to be stripped from the proposed dam foundations to provide a satisfactory surface for placement of fill.

The scarcity of competent foundation rock and the general instability of slopes makes damsite location within the Northern Coast Ranges an extremely difficult problem.

Coast Range Foothills. Foundation conditions in the Coast Range Foothills are generally adequate for construction of earthfill dams. Resistant rock units of the Cretaceous bedrock series such as sandstone and conglomerate provide the best foundations. Mudstones and shales are much more susceptible to weathering and are less desirable but nevertheless, provide an adequate foundation for fill dams. The depth of overburden in the Cretaceous rock is generally quite shallow and landslides are infrequent and of minor importance.

The poorly consolidated sediments of the Tehama formation will provide fair foundations for low earthfill structures planned as part of the Westside Feeder System. Leakage through pervious lenses or interbeds along with uplift due to seepage forces appear to be the most serious construction problems in the Tehama formation.

Construction Materials

Klamath Mountains. Impervious construction materials near the proposed dams on the Trinity and South Fork Trinity Rivers consist of Tertiary sediments and recent accumulations of slopewash and residual soil. The Tertiary sediments of the Weaverville formation will provide the bulk of the impervious fill for Eltapom and Helena damsites, while the Burnt Ranch and Ironside dams will utilize residual soil and slopewash in the impervious sections.

Hard, resistant igneous and metamorphic rock units located near the proposed sites will furnish ample quantities of high quality rockfill and riprap.

Alluvial sand and gravel in the channels of major streams along with dredger tailings from gold mining operations are the only readily available sources of pervious fill. Sufficient quantities for filter zones and concrete aggregate for appurtenant structures have been outlined during the reconnaissance study.

Northern Coast Ranges. Impervious materials in the Northern Coast Ranges consist of soil, slopewash, terrace deposits, and landslide debris derived from weathering of Franciscan rock types. Preliminary exploration test results show considerable variation in the physical properties and indicate that selective excavation will be required to obtain suitable embankment material.

Pervious materials for use in filters and drains for the proposed rockfill or earthfill structures are in short supply. The materials consist of discontinuous lenses of alluvium confined to the channels of the major streams. These gravels are also the only readily available source of concrete aggregate.

Rockfill materials consist of sandstone and greenstone. Areas of competent rock are usually of limited extent so that several separate quarries must be developed in order to obtain sufficient volume of rockfill for a large dam. Sandstone of the Franciscan group is often thinly bedded and contains interbeds or lenses of shale that will tend to break into small sizes when quarried.

Coast Range Foothills. Impervious construction materials in the Coast Range Foothills consist of weathered bedrock and the unconsolidated sediments of the Tehama formation. Soil and slopewash derived from mudstone and shale are present only in very limited quantities and should be used only where the Tehama formation materials are unavailable. The Tehama sediments consist predominantly of silty clay and clayey gravel and are well suited for impervious to semi-pervious fill. Virtually every large damsite in the Coast Range Foothills is within a reasonable distance of this source.

Pervious materials suitable for filters and drains as well as concrete aggregate are in very short supply. Extensive pervious deposits are located only in the channels of major streams and the total quantity of local stream alluvium appears to be insufficient for the construction of the proposed projects. Additional pervious materials can be imported from the Sacramento River channel.

Rockfill sources consist of thin beds and lenses of sandstone and conglomerate which will furnish only limited quantities of suitable material. Few damsites in the foothills have been considered for rockfill structures owing to the scarcity of quarry rock.

Tunneling Conditions

Tunneling conditions as compiled for this report are to be used only in preliminary planning and design. Geologic conditions and rock load factor assigned to various tunneling zones are described in Department of Water Resources Bulletin 78, Appendix C, entitled "Procedure of Estimating Costs of Tunnel Construction". The tunneling cost curves included in Bulletin No. 78 were used for preliminary estimates of the North Coastal area tunnels.

Klamath Mountains. Tunneling conditions in the Klamath Mountains will generally be quite favorable. No unusual tunnel driving difficulties are anticipated in the igneous or metamorphic rock types. The average conditions will vary from massive, moderately fractured to schistose and moderately blocky and seamy. Unfavorable tunneling will be encountered only in fault zones and in serpentine. This material will range from very blocky and seamy to completely crushed and heavy steel support will be required. Faults and serpentine are found in relatively narrow zones and should constitute a minor portion of the total tunnel length. Inflow of ground water into tunnels in the Klamath Mountains will generally be moderate. Highest inflow will occur in brecciated zones under considerable depth of cover.

Northern Coast Ranges. Tunneling conditions in the Northern Coast Ranges will be highly unfavorable and considerable construction difficulties

are anticipated. Rock units of the Franciscan group have been intensely fractured and sheared and have been locally reduced to a clay gouge. The best tunneling conditions will be encountered in areas of high sandstone-shale ratio, or in greenstone. Areas of moderately fractured, relatively competent rock are of limited extent and will affect only a minor portion of the proposed tunnels. The major portions of the North Coast Range tunnels will penetrate thinly bedded, closely fractured sandstone and shale. Tunneling conditions in this material are expected to be very blocky and seamy to completely crushed. Closely spaced steel ribs will be required in this material. The greatest tunneling difficulty will be encountered in fault zones, sheared shale, and in serpentine. Tunneling conditions in these zones will be completely crushed. Crushed, gougy material is expected to act as squeezing ground under a moderate depth of cover necessitating circular yielding steel ribs or invert support. Although relatively minor portions of the proposed Northern Coast Ranges tunnels will penetrate zones of highly incompetent crushed rock, the cost of tunneling in these zones may constitute a significant percentage of the total tunneling cost. The inflow of water into the proposed Coast Ranges tunnels is expected to be moderate to high. The highest inflows will occur in crushed and brecciated rock where the water is able to percolate downward through interconnected fractures.

Coast Range Foothills. No tunnels have been planned in the Coast Range Foothills. Tunneling conditions in the Cretaceous bedrock will be stratified to slightly blocky under moderate depths of cover.

Landslide Conditions

One of the most noticeable topographic characteristics of the North Coastal area is the large number of landslides. In addition to the literally thousands of relatively small slides, some of very large magnitude have been observed. Over 200 of these slides have been studied and mapped along the Eel River system to obtain an estimate of the volume of material that could move into the proposed reservoirs. Most of the slides are slow-moving earth flows or "mud glaciers" which would gradually reduce storage capacities of reservoirs. However, under full reservoir conditions,

followed by rapid drawdown, the saturated toes of the slides could move more rapidly and possibly generate waves of sufficient magnitude to damage earthen dams.

A more comprehensive discussion of landslides along the Eel River and Middle Fork Eel River is presented in Volume II as Attachment B, "Engineering Geology of Landslides along the Eel River". This report describes the nature of the Eel River slides and presents data on volumes of slide material and loss of storage capacity for each of several reservoirs proposed.

Seismicity

The seismicity of an area is a measure of seismic activity per unit time. Most accounts of seismicity have been general discussions of the size and number of earthquakes in an area during the time of historical record. Two quantitative values are used to define the size of an earthquake:

Magnitude. Magnitude is a number derived from measurements of records from seismic instrumentation. The largest earthquakes have magnitudes near 8-3/4, the smallest measured with sensitive seismic equipment near the source is about -2. Two scales are used in this country. The Richter Magnitude is used here and throughout the world except by the U. S. Coast and Geodetic Survey. Their scale is similar for distant earthquakes.

Intensity. The intensity of damage in cultural areas ranges from I to XII. These values represent "barely perceptible" to "total destruction". The maximum intensity observed may be roughly correlated to a magnitude (see Richter 1958, Page 353, or Gumensky, 1957). The modified Mercalli scale is used in this country, the Mercalli - Cancani - Sieberg scale in Europe. They are similar scales.

For localities and times where seismic instrumentation is unusually plentiful, quantitative seismicity maps have been constructed. They are in terms of energy released per unit area per unit time or numbers of earthquakes within a specific range of magnitudes per unit time per unit area. Energy released is derived from a theoretical formula which has been modified by seismic observations of nuclear explosions of known yields. A quantitative contoured seismicity map for this region was presented by Niazi, 1964.

Except for the Eureka area, earthquakes in the North Coastal area are infrequent as compared to other areas of the State. Those which have occurred are of low to moderate intensity but records are often poor because of the lack of sufficient instruments throughout the area. Observations on the effects of earthquakes which are needed to rate intensities are also poor because the

interior areas have been so sparsely populated in the past. Most of the recorded earthquakes occur along the coastal areas particularly off the coast of Eureka. Another center of minor activity is in the Clear Lake region. Plate 2 shows the epicenters of earthquakes which have a Richter Magnitude of 4 or greater for the period 1934 to 1961. Some large magnitude earthquakes which occurred prior to 1934 are also shown. Major damsites studied during this investigation are plotted to show locations relative to active areas.

Most of the earthquakes along the coast are related to activity along the San Andreas fault, the only known active fault in the North Coastal area. Although, as is generally believed, accumulation of strain in the earth's crust along the San Andreas fault is caused by a northward movement of the California Coast (west of the fault), it is not known if similar forces are acting along the interior paralleling faults (see Plate 2).

Although historic data are poor and location of epicenters are not accurate for many isolated shocks, some generalizations of seismicity are possible in each of three provinces -- The Klamath Mountains, Northern Coast Ranges, and Coast Range Foothills. C. F. Richter (Richter 1959) has divided the State into several seismic regions based on the expected probable maximum seismic intensity as measured on the Modified Mercalli scale of intensity. Values assigned to the various areas apply to the predominant rock type. Local alluvial fill areas in a mountainous area, for example, might have higher seismic intensity.

Klamath Mountains. The Klamath Mountains province is an area of low seismicity as compared to other areas in the North Coast. C. F. Richter places the Klamath Mountains in the category of lowest expected probable maximum seismic intensity, which is VI. On the Modified Mercalli scale, VI is described as: "Felt by all; many frightened and run outdoors; falling plaster and chimneys; damage small". According to Gumensky's correlation chart of intensity and magnitude scale (Gumensky 1957), an earthquake of intensity VI would approximately correspond to 5 on the Richter scale, and ground accelerations could be slightly over 0.06g. Plate 2 shows the epicenters of a few earthquakes of this magnitude and less, which have occurred during the period 1934 to 1961.

Northern Coast Ranges. Most of the Northern Coast Ranges province, north of Clear Lake, is considered slightly more active than the Klamath Mountains. According to C. F. Richter's seismic regionalization map, the

expected maximum probable seismic intensity is VII. On the Modified Mercalli scale, VII is described as: "Everybody runs outdoors; damage to buildings varies, depending on quality of construction; noticed by drivers of automobiles". The coastal area near the San Andreas fault and the Eureka area are in intensity zone VIII. As shown on Plate 2, several earthquakes of magnitude 6 and greater have occurred off the coast. In the interior mountainous areas, earthquakes of a magnitude greater than 5 have not been recorded but major earthquakes in the Eureka area could occur and trigger damaging rock and landslide areas in the interior; hence, accelerations of up to 0.1g could be expected. Ground accelerations in areas close to Eureka could no doubt exceed 0.1g.

Coast Range Foothills. This area is similar seismologically to most of the Northern Coast Range. Earthquakes are infrequent and of low to moderate intensity. The expected maximum probable seismic intensity of VII would apply to consolidated rocks of Cretaceous age. Higher intensities could be expected on alluvial fill areas found toward the center of the valley.

CHAPTER II. MIDDLE FORK EEL RIVER PROJECTS

The engineering geology of possible projects on the Middle Fork Eel River is discussed in this chapter. The projects, shown on Plate 1, include Dos Rios Dam and Reservoir, Spencer Dam and Reservoir, Franciscan Dam, and the Eel-Glenn and Elk Creek Tunnels. Geologic maps, cross sections, and location of construction materials for these projects are shown on Plates 3 through 8.

Projects considered as alternatives and as additions to the above, such as Mill Creek Dam, have not been as thoroughly investigated as the featured projects. These other projects are discussed herein, but no maps are included. These projects include Upper Mina Dam and Mina Tunnel, which would divert water to Spencer Reservoir, Upper Etsel Dam, Mill Creek Dam, and Mill Creek Tunnel (Round Valley drainage tunnel).

Other damsites which were investigated, but are not being further considered because of poor foundation conditions, are tabulated at the end of this chapter in Table 6. These damsites include Lower Etsel and Jarbow on the Middle Fork Eel River.

Dos Rios Damsite

Dos Rios Reservoir would permit diversion of surplus waters from the Middle Fork Eel River to the Sacramento River drainage via the Eel-Glenn Tunnel or into the Clear Lake drainage via Elk Creek tunnel and English Ridge Reservoir and the Garrett Tunnel as shown on Plate 1.

The investigation of Dos Rios damsite consisted of reconnaissance geologic mapping of the site, the proposed spillway, and reconnaissance of the potential borrow areas. Plate 3 shows the geology of Dos Rios damsite and Plate 6 shows the locations of various types of construction materials.

Location and Access

Dos Rios damsite is located in Sections 4 and 9, T21N, R13W, MDB&M, about 2 miles upstream from the confluence of the Middle Fork Eel River with the main Eel. Topography is shown on the Laytonville quadrangle, published by the U. S. Geological Survey at a scale of 1:62,500 and a contour interval of 50 feet. Geologic mapping of the site was done on Department of Water Resources' photogrammetric contour maps with a scale of 1 inch to 400 feet and 1 inch to 100 feet and with a contour interval of 20 feet. Geologic mapping of the borrow areas was done on an enlargement of the USGS quadrangle sheet with a scale of 1:24,000.

The site is easily accessible by the Longvale-Covelo Road which passes across the right abutment at an elevation of about 1,600 feet. The crest of the left abutment can be reached by an abandoned logging road.

Foundation Conditions

Right Abutment. The right abutment has an average slope of about 35° . The topography near the axis and in the upstream toe area is relatively uniform with few shallow canyons. In the downstream toe area, the abutment slope is dissected by many irregular ravines with nearly vertical to overhanging cliffs near the stream channel.

The abutment is underlain by Franciscan graywacke sandstone with interbeds of black, carbonaceous shale (see Plate 3). The approximate ratio of sandstone-shale observed along the stream channel is 85:15. The graywacke sandstone, exposed in the channel section, is a hard, fine-grained and highly resistant unit. Interbeds of shale are usually thin and not continuous over a distance of more than a hundred feet. Shale lenses are often crushed and deformed, owing to their relatively incompetent nature as compared to the sandstone. Along several shear zones in the channel, the shale is crushed and altered to a clayey gouge with very little apparent shear strength. However, gouge seams are local and discontinuous and do not detract from the overall foundation stability.

The strike of the strata varies from N60-70W in the downstream toe area to about N30-40W near the axis to nearly east-west in the upstream portion of the proposed dams. The bending of the strike suggests a broad warp. The dip of the strata is to the southwest, generally at a very steep angle. The dips appear to be somewhat steeper in the upstream portions of the site.

No faults of any consequence were mapped on the right abutment. Several shears were noted, confined primarily to less resistant shale interbeds.

The following three prominent joint sets were recognized along the right channel section.

1. Bedding joints - parallel to dip and strike of the strata. Attitude varies from N30W to nearly east-west, dipping steeply to the south and southwest 40° to 80°. Joint spacing averages 1 to 2 feet.

2. Joints essentially parallel to the strike of the sedimentary rock, but with an opposite dip - this joint set was observed along the entire right channel and appears to be very persistent in the foundation area. The strike of these joints varied from N30W to east-west and the dip from 40° to 80°, to the north and northeast.

3. Joints normal to the strike - this appears to be the most prominent set of fractures although not as closely spaced as the other two sets. Joint spacing is on the average about 10 feet. A number of gullies on both abutments are controlled by this joint set. Slickenside was noted on some of the more prominent fracture planes indicating a certain amount of shearing.

Nearly all joints in the channel section are quite tight and show little weathering or alteration. Several joints contained small seeps at the base of the abutment. Higher on the abutment the joints are open to a considerable depth in deeply weathered rock, probably as much as 50 feet normal to the slope.

Outcrops of fresh rock are confined to the lower 100 feet of the right abutment with the remainder of the abutment slope partially covered by soil and colluvium. The intensity of weathering of the foundation rock near crest elevation is well illustrated in road cuts along the Covelo Road. The intensity of weathering on the right abutment is generally somewhat more pronounced than on the opposite slope. The right abutment faces south, receiving the maximum of sunlight, and hence experiences the highest daily temperature fluctuations. These conditions promote mechanical breakdown of the stratified sandstone and result in accumulation of talus and slopewash.

Foundation preparation on the right abutment under the impervious section will require stripping of soil, slopewash, talus, and loose rock in addition to removal of 10 feet of weathered rock or an overall average of 15 feet. The lower 75 to 50 feet of the abutment slope are not covered by colluvium or soil, but will require extensive hardrock shaping to provide an even surface for placement of impervious fill. About 5 feet of irregular sandstone cliffs will be removed in this interval.

Interbeds of sheared, weathered shale and minor shear zones will require over-excavation in the cutoff section to a depth of 3 to 5 feet and will be filled with concrete. This dental work is expected to constitute a very minor increment of the overall foundation preparation.

Foundation stripping under the rockfill portion will consist of excavation of all soil, colluvium, and talus, and will average about 5 feet overall.

Channel. The width of the stream channel at Dos Rios damsite averages about 150 feet. At the time the site was initially mapped (April 1962) virtually the entire channel section was under water. In late summer and fall, the streamflow diminishes considerably and the width of flowing water becomes much less.

Outcrops are confined to the base of the abutments extending only a short distance into the stream channel which is filled with alluvial sand and gravel. At no point are outcrops continuous across the channel; however, attitudes of the strata appear to be in concordance on both sides of the river and there appears to be no fault hidden under the alluvial fill. Based on this evidence, the channel is believed to be underlain by hard, stratified sandstone with thin shale interbeds.

No estimate of the depth of fill could be made owing to high water. However, in a previous reconnaissance study average depth of fill was estimated at 15 feet with a maximum of 25 feet in scour or potholes.

Stripping in the stream channel under the cutoff section will consist of removal of all stream alluvium in addition to 5 feet of loose and weathered rock. Shaping of the irregular bedrock surface will be required to insure proper contact of impervious fill with foundation rock. Interbeds of sheared gougy shale should be excavated to a depth of about 3 feet and filled with concrete.

Stripping under the rockfill section will consist of removal of the stream alluvium and accumulations of loose weathered material at the base of the abutments. Although the alluvium should not endanger the overall dam stability, it should be removed to facilitate inspection of the underlying bedrock.

Left Abutment. The left abutment has a relatively even slope, averaging about 35° , but by a number of shallow ravines or notches. The abutment slope faces north and receives the minimum of direct sunlight, resulting in moderate daily temperature variations. Under these conditions the foundation rock is not subjected to intense mechanical breakdown

and has, therefore, only patches of shallow residual soil and virtually no colluvium or talus in contrast to the right abutment which is covered by extensive, although shallow, colluvium. The left abutment has a moderate vegetation cover which consists primarily of brush and pine trees.

Outcrops are continuous from the channel to the proposed dam crest. It was estimated that rock is exposed on about 80 percent of the abutment slope. Rock types, shears, joints, and other geological features are identical to the right abutment.

Foundation preparation on the left abutment will consist of the following:

1. Impervious section: Stripping under the impervious section will require removal of all soil and loose rock in addition to about 10 feet of weathered and jointed sandstone -- an average depth of 12 feet. Interbeds of sheared shale, prominent crevices, and shear zones will be over-excavated about 3 feet below cutoff and filled with concrete.

Virtually continuous rock exposures will not permit operation of crawler dozers on the left abutment. Nearly all stripping will be accomplished by hardrock methods.

2. Rockfill section: The foundation should be stripped of all soil and loose rock, a total of about 2 to 3 feet.

Soil and a great portion of loose material can be removed by high pressure water monitors. Normal overburden stripping practices would not be applicable owing to rough, rocky terrain.

Summary of Stripping Estimates

Right Abutment	Channel	Left Abutment
<u>Impervious</u>		
15 feet overall -- 5 feet of soil colluvium and talus plus 10 feet of jointed weathered rock. Extensive hard-rock shaping on the lower slope.	20 feet overall -- 15 feet of alluvium and 5 feet of weathered and jointed rock. Some hard-rock shaping is necessary.	12 feet overall -- 2 feet of soil in addition to 10 feet of weathered and jointed rock. Some hardrock shaping.
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Summary of Stripping Estimates (Cont.)

Right Abutment	Channel	Left Abutment
<u>Pervious</u>		
5 feet overall -- remove all soil, colluvium, talus, and loose rock.	15 feet over entire section -- remove all alluvium and loose rock.	3 feet overall -- strip all soil and loose rock.

Spillway

Three alternate spillway locations have been considered during the field reconnaissance:

1. Side channel - right abutment
2. Side channel - left abutment
3. Saddle spillway north of the right abutment

The selection of the most favorable spillway site is based primarily on the crest elevation of the alternate proposed dams, which control the total volume of material to be excavated.

Side channel spillways on either abutment are about equally favorable. However, different dam crest elevation schemes will favor one or the other owing to irregular topography. In general, the right abutment appears to be somewhat better suited for a side channel spillway at a lower elevation, while the left abutment is better suited for a higher elevation plan.

The entire excavation will be in hard Franciscan sandstone with occasional thin shale interbeds. The rock is moderately jointed, with an average fracture spacing of about 2 feet. The entire excavation will be by hardrock methods with an estimated 75 percent of excavated material suitable for rockfill. Side slopes should be stable on a 1/2:1 ratio in fresh sandstone and about 1:1 in the upper 50 feet where the rock is weathered and joints are open.

The dip of the bedding is in a southerly to south-westerly direction and varies from 40° to 80°. This condition would favor the left abutment location as the bedding would dip into the slope, whereas on the right abutment the beds dip into the excavation and may cause rockfalls or slipouts. On the average, however, the angle of the stratification is generally steeper than the slope of the proposed excavation and the danger of sliding is relatively minor and confined to small areas.

The saddle location north of the right abutment would result in a 400-foot deep cut for the crest elevation of 1616. The volume of material in the saddle would by far exceed that of a side channel excavation. Rock types mapped in the saddle include sandstone, shale, greenstone, glaucophane schist, and a thin veneer of recent sediments. The heterogeneous nature of the rock units indicates that the saddle is located outside the limits of the massive sandstone section which forms the damsite, and is underlain by less competent rock.

Side slopes should be stable on a 1:1 ratio with berms every 50 feet. Locally, intensely sheared rock may be encountered and will require additional excavation or treatment to minimize the danger of slope failure. Virtually the entire saddle spillway cut will be excavated by hardrock methods. About 25 percent of the material should be suitable for rockfill.

Construction Materials

Impervious Fill. Two sources of impervious fill were briefly investigated during the field reconnaissance: (1) Tertiary sediments which consist of shale, sandstone, and conglomerate, and (2) landslide debris derived predominantly from Franciscan shale. The two materials sources have extremely diverse physical properties which will affect their suitability in the dam section. Location of these materials are shown on Plate 6, "Location of Construction Materials".

Tertiary sediments are located in a northwest-trending belt east of the proposed site, and consist of poorly indurated sandstone, shale, and conglomerate. This area is indicated as I-8 on Plate 6. A preliminary estimate indicates that an adequate volume of this material can be obtained within a 2-mile radius from the site.

No tests were performed to date to determine the physical characteristics of this material, and little is known of its suitability as impervious fill. Overall, the Tertiary sediments appear to have a rather low percentage of fines and may have a relatively high permeability. Their average composition is probably that of a gravelly, silty sand. The upper 20 feet of this material is deeply weathered and

has a higher concentration of fines. This upper zone appears to be well suited for impervious fill.

Extensive landslide debris are located about 2 miles west of the proposed axis on both the north and south sides of the Middle Eel Canyon (areas I-9, Plate 6). The landslides are confined to a north-south trending belt of Franciscan shale which is cut by a major fault zone. An adequate volume of this type of material appears to be present within a 2-mile radius from the site. Based on field observation, this material appears to have a high percentage of fines, in contrast to the Tertiary sediments, but may have a rather low shear strength. No tests have been conducted on slide debris from this locality.

Rockfill. The massive lens of sandstone which forms the dam-site abutments appears to be an excellent source of rockfill for the proposed structure. A virtually unlimited quantity of rockfill can be quarried at the site with a minimum haul distance (area R-5, Plate 6).

The sandstone is hard and moderately jointed -- fracture spacing averages about 2 feet. It was estimated that the sandstone unit contains roughly 15 to 20 percent of thin shale interbeds which could not be used in the rockfill section. Weathering is relatively shallow and should be confined to the upper 5 to 10 feet and along prominent joints. Overall, the depth of weathering on the left abutment is somewhat less extensive and an estimated 80 percent of the canyon slope is underlain by visible sandstone outcrops.

The most favorable quarry location appears to be on the left abutment immediately adjacent to the dam. As many as three or four bench quarries could be opened, one above another as construction progresses, to eliminate uphill haulage, or one single large quarry could be used just above the fill section to a maximum elevation of 2,000. Above elevation 2,000, highly fractured chert, greenstone, and shale occur which are not suitable for rockfill. Salvage from side channel spillway excavations could also be used as rockfill.

Filter Material. Limited quantities of river alluvium are located at the confluence of the Eel and Middle Eel Rivers about 3 miles west of Dos Rios damsite and extend downstream from the confluence (areas P-7, Plate 6).

About 1.2 million yards of alluvial sand and gravel are located within 3 air miles of the site. This material will require considerable screening to produce suitable filter and an accurate estimate of usable volume cannot be made prior to testing of a representative section of this material.

Outlet Works

Either abutment will provide excellent tunneling conditions for a diversion tunnel. However, exploration is necessary to determine the preference of one abutment over another. The diversion tunnel will be entirely in hard, moderately jointed sandstone with occasional thin shale lenses.

Conclusions

1. Foundation conditions at Dos Rios damsite are excellent, and no unusual construction difficulties are anticipated.

2. The site is suitable for a rockfill dam with an impervious fill core.

3. Adequate volumes of construction materials appear to be available.

(a) Rockfill can be quarried at the site in sufficient quantity for the proposed dam.

(b) Adequate volumes of impervious materials of two contrasting types are found within a 2-mile radius. These are poorly consolidated Tertiary sediments and landslide debris. Based on preliminary geologic reconnaissance, weathered Tertiary sediments should provide the best source of impervious fill.

(c) Stream alluvium suitable for filters and drains is found in discontinuous bars of limited quantity at the confluence of the Middle Eel and Eel Rivers and extends several miles downstream.

4. Side channel spillway on either the left or the right abutment appears to be most feasible. Final selection of spillway location will depend on the crest elevation. The excavation on either abutment will be in hard moderately jointed sandstone. As much as 80 percent of the excavated material should be salvagable for rockfill.

Recommendations

1. A thorough construction materials investigation is necessary for a proper evaluation of the feasibility of the Dos Rios damsite.

(a) Potential sources of impervious fill in both the Tertiary sediments as well as the slide debris should be sampled and tested to determine their suitability as fill material.

(b) Sandstone in the damsite canyon should be investigated to determine its strength and quarry characteristics. These tests should determine whether or not this material is usable for construction of a high rockfill dam.

2. Foundation exploration is less critical than construction materials investigation and should be initiated after the availability of fill material has been established.

Spencer and Franciscan Damsites

Spencer damsite lies in the NE 1/4 of Section 1, T22N, R12W, MDB & M, on the Middle Fork Eel River. The site is about 6 air miles east of Covelo, Mendocino County, and access to the site from Covelo is mostly over unpaved roads.

Franciscan damsite is in Section 28, T23N, R12W, MDB & M, on Short Creek, tributary to Mill Creek, which in turn is tributary to the Middle Fork Eel River. Franciscan site is about 3-1/2 air miles north-east of Covelo. Access is over paved roads. Both sites are shown on the USGS Covelo quadrangle, with a scale of 1:62,500 and a contour interval of 100 feet.

The maximum heights of dams considered at the Spencer and Franciscan sites are 385 feet and 310 feet, respectively. Franciscan Dam would be necessary to prevent stored waters from flooding Round Valley. Water from Spencer Reservoir could be diverted to the Sacramento Valley, through the proposed Spencer-Thomes Tunnel, or into the English Ridge Reservoir and Clear Lake drainage via Dos Rios Reservoir and Elk Creek Tunnel.

The geologic investigation of Spencer and Franciscan sites was conducted intermittently from 1957 to 1961. The work performed consisted of geologic mapping of the sites, a construction materials investigation, foundation drilling, trenching, field permeameter tests, and a resistivity survey. Materials exploration included drilling of 44 auger holes and laboratory testing. Foundation drilling included six diamond drill holes at Spencer site and four at Franciscan site. In addition, Spencer Meadow at the Spencer damsite was explored with eight auger holes, and five auger holes were drilled at the spillway location. A summary of all foundation diamond drilling performed is presented in Table 2, "Summary of Exploration, Spencer Damsite", and Table 3, "Summary of Exploration, Franciscan Damsite".

Exploration of Foundation Rock (Spencer Damsite)

Six diamond core holes were drilled at Spencer site. Hole RA-1 was drilled on the right abutment to explore depth to firm rock. Angle

holes RC-1 and LC-1 were drilled toward each other to cross the channel near the axis of the proposed dam. Holes LA-1 and LA-2 were drilled in Spencer Meadow. Hole LA-3 was drilled near the middle of the left abutment near the axis of the proposed dam (see Table 2). Location of drill holes and geologic units are shown on Plate 4, "Geologic Map and Sections".

Two trenches, T1 and T2, were excavated to explore the depth of stream fill on a terrace just above the channel on the right abutment.

Eight 10-inch-diameter auger holes, AH-1 through AH-8, were drilled in Spencer Meadow. Five 10-inch-diameter auger holes were drilled along the spillway crest to explore depth to sound rock. Two of these holes were used for field permeameter tests.

A resistivity survey was performed at Spencer Meadow to help determine the depth and extent of the weak clayey material underlying the meadow.

Foundation Conditions (Spencer Damsite)

Right Abutment. The right abutment is fairly regular in configuration, with a slope of 30 percent except for a small, flat terrace near the channel. The abutment is mostly underlain by moderately jointed sandstone, occasionally interbedded with thin shale beds. Shale predominates over the sandstone in some places on the abutment, and occasionally the sandstone coarsens to a conglomerate. Small discontinuous bodies of chert and greenstone are also present. The bedrock is mantled by loose, brown, clayey soil and the number of outcrops decrease progressively with elevation. Small shears in the rock are very common. Water tests indicate the fractures in the rock are generally open, and grout take should be moderate to high (see Table 2). Fractures in drill hole RA-1 seemed to open up under higher water pressures, particularly in the upper portions of the hole where the rock was intensely weathered.

Average stripping estimates for cutoff on the right abutment are 10 feet with some overexcavation required in sheared, gougy seams. However, no unusual construction problems are anticipated. Stripping estimates are summarized at the end of this section.

Channel Section. The width of the channel section beneath the proposed dam is about 300 feet. This width includes relatively flat, narrow terraces which occur on both sides of the stream (see Plate 4). Chert is the principal rock type on the left channel side upstream from the axis. Approximately at the axis, the chert is in contact with sandstone and shale. Along this contact, considerable shearing and deformation of the shale and chert is evident. On the right channel side alternating beds of sandstone and shale are exposed which strike directly into the chert body. It thus appears that there is a lack of structural continuity across the stream and it is inferred that a shear zone exists along the channel. Based on drilling information, the shear zone is characterized by gougy shale which has undergone intense deformation as it was confined and was crushed between two much more resistant rock units -- chert on the left abutment and sandstone on the right. Both drill holes LC-1 and RC-1 encountered a considerable amount of soft sheared shale beneath the channel.

Estimated average stripping beneath the impervious section is 2 feet of alluvium and 4 feet of rock. In addition, special cleaning out of soft sheared shale may be necessary. Water losses during water pressure tests were generally high in the channel drill holes, and high grout takes should be anticipated.

Left Abutment. The left abutment has a regular, steep slope of about 40 percent to Spencer Meadow or elevation 1,600 where the slope flattens to an average of 20 percent. Above Spencer Meadow, or elevation 1,700, the slope again steepens. There is also a small, flat terrace just above the river on the left abutment.

The entire left abutment below Spencer Meadow is formed by thin-bedded chert with some interbedded shale. Although some minor slumping of the thin-bedded chert was observed, most of this portion of the abutment is stable and will form a suitable foundation for the proposed dam. Stripping estimates in this section of the abutment beneath the impervious section are 5 feet.

The Spencer Meadow portion of the left abutment is underlain by slopewash to an average depth of about 15 feet and an inferred maximum near the toe of the dam of 40 feet (see Plate 4). Test results indicate that this material has very low strength and should be removed from the dam foundation.

Summary of Triaxial Test Results
on Three Samples from Spencer Meadow

	:		:	Dry	:		:		:	Appt.
Drill	:		:	Dens.	:	Moist	:	Deg.	:	Cohesion
Hole	:	Depth ft.	:	11CF	:	%	:	Sat %	:	ϕ°
	:		:		:		:		:	T/SF
AH-8	:	6 ⁸ to 8 ⁴	:	95.8	:	25.2	:	80.5	:	2.6
AH-8	:	12 ⁶ to 13 ⁵	:	102.8	:	26.0	:	98.1	:	2.2
LA-2	:	4 ⁰ to 5 ⁰	:	109.8	:	23.7	:	100.	:	5.5
	:		:		:		:		:	0.22

Slope stability and drainage of the cut slope in the weak saturated clay would present some construction difficulty. Preliminary estimates based on the three shear tests indicate that the cut should stand on a 2-1/2:1 slope during the construction. A ditch leading from the meadow and around the toe of the dam will provide drainage for both the dam fill as well as for the clay. The excavation in the clay should be backfilled with suitable filter and embankment material to prevent subsequent sliding of the clay onto the toe of the dam.

Water losses during water pressure tests in hole IA-3, which penetrated in-place chert and minor shale, were generally high. Grout takes in the chert were estimated to be high.

Summary of Stripping Estimates
Spencer Damsite

Location	:	Average stripping estimates	
	:	in feet	
	:	For cutoff	: Pervious sections
Right abutment		5 soil, 5 weather rock	5 soil
Channel		2 alluvium, 4 rock	2 ft. alluvium
Lower left abutment (to elevation 1,600)		5 soil, 5 disjointed	5 soil
Upper left abutment (above elevation 1,600)		15 soil and loose rock	15 soil

Exploration of Foundation Rock (Franciscan Damsite)

Four diamond core holes were drilled at Franciscan site. Hole RA-1 was drilled on the right abutment to determine depth to firm rock. Angle hole LC-1 was drilled to cross the channel to explore for shearing parallel to the channel. Holes LA-1 and LA-2 explored depth of overburden on the left abutment (see Table 3).

Foundation Conditions (Franciscan Damsite)

Rock at the site consists of Franciscan sandstone with minor conglomerate, shale, lenses of chert, and pods of serpentine. The average strike of these rocks is about N35°W. The dip is usually steep and generally is to the west, although a number of small folds control the actual direction of dip. The strike of the beds intersect the axis of the dam at an angle of about 20°. Geology of Franciscan damsite is shown on Plate 5, "Geologic Map and Section".

Right Abutment. The right abutment has a rather uneven configuration, with an average slope of about 35 percent. In general, the abutment is steepest near the channel, and the slope flattens progressively higher on the abutment.

The abutment is underlain by Franciscan sandstone, containing thin beds of sheared shale. Small irregular-shaped lenses of thin-bedded chert also occur on the abutment. The sandstone outcrops are common near the channel, but outcrops high on the abutment are rare. All the rock encountered in hole RA-1, drilled to a depth of 76.5 feet, was considerably weathered.

Average stripping estimates for cutoff on the right abutment are 12 feet.

No water tests were performed in hole RA-1, but judging from water losses during drilling, it is estimated that grout take will be moderate.

Channel Section. The width of the channel section along the axis is only about 40 feet. Sandstone which contains bands of sheared shale and chert are well exposed along the channel section.

Estimated stripping for cutoff is 5 feet of weathered rock. Special treatment of some of the most sheared shale bands may be required. Water tests in hole LC-1 indicate that below a depth of about 30 feet the rock is tight. Below 30 feet, actually only 20 feet perpendicular to the ground surface, grout take should be low; above this depth it is estimated that grout take will be moderate.

Left Abutment. The left abutment has a slope of 50 percent to about elevation 1,560. Above elevation 1,560 the slope is much gentler and the axis crosses two small saddles. The geologic map, Plate 5, shows two small dikes in the saddles. If the dam is carried to elevation 1,700, as has been proposed, the embankment would be continuous along the left abutment across the saddles. The left abutment is underlain by sandstone, with some sheared shale. Two small pods of serpentine are present downstream from the axis.

Depth of weathering on the left abutment is believed to be greater than on the right, particularly above the break in slope at elevation 1,560. Average stripping estimates for cutoff on the left abutment are 20 feet.

Grout take in the left abutment is estimated to be moderate, as determined by water losses during drilling operations (see Table 3).

Summary of Stripping Estimates Franciscan Damsite

Location	Average stripping estimates in feet	
	For cutoff	Pervious sections
Right abutment	6 soil, 6 weathered rock	5 soil
Channel	5 weathered rock	3 weathered rock
Left abutment	15 soil, 5 weathered rock	5 soil

Spillway and Outlet Works

Spillway. The spillway for the reservoir which would be created by construction of Spencer and Franciscan Dams would be located 1.5 miles west of Spencer dams site. The proposed spillway is underlain

near its crest by Franciscan sandstone and minor shale and greenstone. Outcrops are absent except near the crest of the ridge that will support the spillway weir. Five 10-inch diameter auger holes were drilled along this ridge, and two permeameter tests were performed. As determined by these tests and approximate computations, the permeability of the rock is in the practically impervious range (less than 1 foot per year).

With the spillway at 1,685 feet, the crest would be about 8 feet above the ground elevation of the lowest point in the saddle. An excavation about 20 feet in depth should expose rock adequate for the foundation of the proposed spillway structure. All of the excavation probably can be made with a blade or ripper. The spoils probably will be unusable as fill in the dam.

It is estimated that cuts in the weathered rock will stand at 1/2 on 1. Lining is recommended from the crest of the spillway down to the major break in slope, a distance of some 800 feet. Additional exploration along the channel of the spillway is needed, so that the necessity of lining can be better evaluated. Floodwaters will discharge, after passing through upper Etsel Flat into the Middle Fork Eel River, about 5,500 feet from the downstream toe of Spencer Dam.

Outlet Works. The proposed outlet conduit at Spencer damsite is a tunnel through the right abutment, which will also serve as diversion during construction. The diameter of the tunnel will be on the order of 18 feet, and the length will depend on the final alignment. The tunnel would pass through Franciscan sandstone and some shale, and generally would be driven perpendicular to the strike. Tunneling conditions generally should be good, but due to the shallow cover, complete lining and support should be anticipated through the tunnel. The tunnel alignment is shown on Plate 4.

A tunnel is also proposed at the Franciscan site. The tunnel alignment would be about 1,400 feet long. Presumably, it would have a minimum diameter. This tunnel would also serve for both diversion and outlet works.

Geologic conditions for the Franciscan diversion tunnel are similar to those at the Spencer damsite. The principal rock encountered would be sandstone with some shale. Chert would be encountered near the upstream portal. Complete lining and support should also be anticipated at the Franciscan tunnel.

Reservoir Area

The entire reservoir will lie within rocks of the Franciscan formation, and leakage is not expected. Loss of storage by silting and landslides will be at least moderate because: (1) streams in this region carry considerable silt loads during high flows; (2) the watershed area generally has deep soil cover; (3) streams in this region have moderate gradients; and (4) landslide areas are very common.

Rapid drawdown of the reservoir will probably aggravate old slides and cause new slides. Because of the landslide potential, extra freeboard would appear to be a reasonable precaution.

Construction Materials

Location of construction materials for both Franciscan and Spencer damsites are shown on Plate 6. Descriptions of the various materials together with estimated volumes are summarized on Table 5 at the end of this chapter.

Impervious Fill. An estimated total of 8 million yards of impervious materials have been outlined in Upper Etsel Flats (area I-3, Plate 6), based on six auger holes and geologic mapping. This material has a composition of silty to gravelly clay and appears to have a low shear strength.

Another potential source of impervious fill for the Spencer Project is located near the crest of Dingman Ridge (area I-5, Plate 6) and consists of residual soil derived from Franciscan slate, phyllite, and schistose sandstone. Based on a preliminary field reconnaissance this material appears to be of somewhat better quality than the Etsel Flat materials consisting of soil and slopewash. Approximately 20 million cubic yards of material are available from Dingman Ridge in the area outlined.

Laboratory testing of Upper Etsel Flat materials consists of one gradation analysis, and one compaction test. No secondary tests have been performed on this material. Further exploration and testing is required both in the Dingman Ridge and Upper Etsel Flat areas for a proper evaluation of the quality as well as quantity of potential impervious materials for the Spencer Project.

Impervious materials are also available in a portion of Williams Valley east of Short Creek (area I-1, Plate 6). Ten 18-inch diameter auger holes, ranging in depth from 10 feet to 25 feet were drilled to explore this area. The material near the surface is a brownish clay of low to moderate plasticity. The clay has an average thickness of 8 feet, and is usually underlain by saturated silty sand or silty gravel. Water levels in the auger holes in September 1959 ranged in depth from 7 feet to more than 25 feet. Water levels probably would be higher than this during the wet season. Providing high water does not interfere with operations, the clay in area 2 probably would be suitable for the impervious core of a fill dam. The average distance to the Franciscan site is 1.5 miles with an easy haul. The air distance to the Spencer site is about 3.0 miles with a much greater distance over poor existing roads. The clay in area 2 is probably the most suitable impervious material available for the Franciscan site. Approximately 3 million cubic yards of material have been estimated to be available in this area.

Pervious Fill. Pervious construction materials are in short supply in the Spencer Project area. A volume of stream sand and gravel (3 million cu. yds.) for construction of the Franciscan Dam has been located along Short Creek (areas P-1 and P-2).

Pervious materials available for the Spencer damsite consist of terrace gravel in the Lower Etsel Flat (area P-5), with an estimated volume of 1,600,000 cubic yards, and stream alluvium from the channel of Mill Creek and Short Creek in Round Valley (areas P-3 and P-4) with a volume of 1,100,000 cubic yards. Pervious materials required for a 365-foot-high (crest elevation 1,705) "thick core" Spencer Dam are

estimated to be at least 4,400,000 cubic yards. Thus, additional pervious materials must be located for construction of Spencer Dam. Additional pervious material sources along the Middle Eel River channel consist of discontinuous lenses or bars of stream alluvium and terrace deposits. No estimate on the volume of this material is available to date; however, this additional source is not expected to provide more than about 1 million cubic yards of fill.

Rockfill. No intensive investigation was undertaken to locate an adequate source of rockfill for Spencer Project. A satisfactory rip-rap source has been outlined south of the site (area R-1, Plate 6) with an estimated volume of 1,500,000 cubic yards of high quality rock.

A potential quarry area for rockfill lies immediately to the south of Spencer damsite (area R-2). The rock is predominantly a Franciscan greenstone which forms a steep, heavily forested ridge to an elevation of 2,500 feet. Other rock present and comprising about 25 percent of the total are chert, phyllite and slate. In outcrop the rock is a closely fractured, somewhat foliated greenstone which is deeply weathered and intensely oxidized along fractures. The degree of fracturing in exposed outcrop appears to be accentuated by the solution of secondary cementing material, as numerous cavities and open irregular interstices were noted, apparently indicating secondary calcite mineralization. In its weathered state, the rock breaks up into roughly equidimensional fragments about 4 to 6 inches in diameter. A light hammer blow will generally break the rock along incipient fractures which are coated with iron and manganese oxide. The zone of weathering probably extends to an average depth of about 30 feet, but is suspected to be highly irregular owing to zones of intensely fractured or sheared rock and lenses of sediments.

Based on reconnaissance geologic study, the upper 30 feet of quarry area R-2 will have to be stripped and wasted. Material from this zone will have a high percentage of fines and will contain rock of relatively low shear strength. Rock immediately below 30 feet will be considerably weathered and fractured but should be suitable in

"transitional" zones of the dam. This material will contain about 25 percent of rock smaller than 1-inch-diameter and a considerable fraction of weak material. Weathering should be minor at a depth of 50 feet normal to the slope of the ridge and suitable rockfill material should be obtained from this zone. The rock is expected to be moderately jointed and foliated with a considerable portion of fractures healed by secondary calcite and quartz. The bulk of rock obtained from this depth will range from 6 to 4 inches in diameter. About 15 to 20 percent of the excavated material will be less than 1 inch in diameter, and some screening may be required for material placed in the downstream section of the dam. The estimated total usable volume of rolled rockfill material in quarry area R-2 is in excess of 20 million cubic yards.

Summary and Conclusions

1. Foundation conditions at the Spencer and Franciscan sites appear suitable for earthfill dams of the proposed dimensions.

Spencer Damsite. The Spencer site is underlain by thin-bedded chert, sandstone, shale, and greenstone, all of the Franciscan formation. These rocks all provide an adequate foundation except the shale which is generally soft and sheared. The right abutment is formed by sandstone, some shale, and minor amounts of chert and greenstone. Stripping estimates for the right abutment are 5 feet soil and 5 feet weathered rock for cutoff. The channel section is underlain by sandstone, chert, greenstone, and a considerable amount of sheared shale which may require special excavation and backfilling. Stripping estimates for the channel section are 2 feet alluvium and 3 feet rock for cutoff. The left abutment is underlain principally by chert up to elevation 1,600. Above elevation 1,600 the slope flattens, and this portion is underlain chiefly by soft clay to a maximum depth of at least 75 feet. Stripping estimates for the left abutment to elevation 1,600 are 5 feet soil and 5 feet dis-jointed rock for cutoff. Stripping above elevation 1,600 would be 30 or 40 feet of clay for stability. With the axis curved downstream,

stripping probably can be reduced to 15 feet overall on this upper portion of the left abutment.

Franciscan Damsite. The Franciscan site is underlain by Franciscan formation sandstone, irregular interbeds of soft, sheared shale, lenses of chert, and pods of serpentine. The soft shale beds may require some special treatment. Average stripping estimates beneath the impervious section are: for the right abutment - 6 feet soil and 6 feet weathered rock; for the channel section - 5 feet weathered rock; and for the left abutment - 15 feet soil and 5 feet weathered rock. It is estimated that grout take will be moderate.

2. The proposed spillway across a topographic saddle 1.5 miles west of Spencer site is underlain mainly by Franciscan sandstone, which should provide an adequate foundation. Results of permeability tests indicate the narrow spillway ridge should be tight. Cut slopes in the weathered rock should stand at 1/2 on 1.

3. Outlet tunnels which will also serve for diversion during construction are proposed at the Spencer and Franciscan sites. The tunnel alignment at the Spencer site is through the right abutment, and the alignment at the Franciscan site is through the left abutment. Both tunnels will be mostly in sandstone. No serious construction problems are anticipated, but complete support and lining should be planned due to the shallow cover.

4. Landslides are considered a serious problem in the reservoir area. Extra freeboard should be provided.

5. Impervious construction materials of various types are available, but rockfill for Spencer is of unknown quality and pervious materials are in short supply.

Recommendations

Prior to the final planning design stage, additional exploration of the foundation conditions at both sites and of construction materials should be explored. The following specific activities should be included in any further exploration:

1. Subsurface investigation of the proposed rockfill source is recommended as the first stage of any further Spencer Project study.

2. Additional exploration in the area of Spencer Meadow, with consideration given to a curved section, such that low strength material beneath Spencer Meadow, is avoided as much as possible. Exploration should include pits or deep dozer trenches for a precise elevation of the nature of the fill material and to obtain undisturbed samples for further testing.

3. Additional exploration along the Spencer axis in the area north of Spencer Meadow.

4. Additional exploration along the length of the channel section of Spencer damsite to better determine the extent of sheared shale in an upstream and downstream direction.

5. Additional exploration at the spillway location, particularly along the spillway channel.

6. Exploration of borrow materials, particularly of pervious material in area 5.

7. Exploration directed toward better definition of rock conditions in the proposed diversion tunnels at Spencer and Franciscan sites.

TABLE 2

SUMMARY OF EXPLORATION
SPENCER DAMSITE

Founda- tion : Drill : Hole No:	Date Started : Date : Completed:	Location :	Incli- nation : and : Bearing:(ft.):	Total: Depth: Water Losses	Interval Tested: Loss: gpm/ft. @ lbs./in ²	Interbedded sandstone and shale, frequently highly fractured and sheared. Clay and calcite coatings and iron staining is often present.	% Core : Recovery : (excl. of : over- : burden)
RA-1	7-21-59 <u>7-31-59</u>	Right abutment, on axis	55°	83.0	Interval Tested: 15.5' Loss: 0.22 gpm/ft. @ 45 lbs/in ²	Interbedded sandstone and shale, frequently highly fractured and sheared. Clay and calcite coatings and iron staining is often present.	57
RC-1	7-8-59 <u>7-20-59</u>	Right channel, near axis	35°	101.0	Interval Tested: 12.9' Loss: 1.7 gpm/ft. @ 110 lbs./in ²	Interbedded sandstone and shale with numerous shear zones containing fractured sandstone and clay gouge.	73
IC-1	6-29-59 <u>7-7-59</u>	Left channel, near axis	50°	113.3	Interval Tested: 18.4' Loss: 1.9 gpm/ft. @ 60 lbs./in ²	Chert with shale partings is present to about 40 feet. Below this is sheared shale gouge which extends to approx. 60 feet with interbedded greywacke and carbonaceous shale below.	60
IA-1	5-22-59 <u>6-3-59</u>	Left abutment	Verti- cal	127.6	Interval Tested: 22.6' Loss: 1.1 gpm/ft. @ 150 lbs/in ²	Clay, gravel, and boulders to a depth of 58 feet overlie fractured sand- stone and shale, and interbedded sand- stone and argillite.	72
IA-2	6-4-59 <u>6-11-59</u>	Left abutment	80°	76.1	Interval Tested: 13.2' Loss: 2.4 gpm/ft. @ 110 lbs/in ²	Soil and clay to 23 feet overlies soft shale, siliceous shale, and chert.	40
IA-3	6-15-59 <u>6-25-59</u>	Left abutment	65°	100.0	Interval Tested: 15.8'	Thinly interbedded hard, dense chert and shale persists throughout most of the hole. Soft, fractured shale and greenstone are also present.	45

TABLE 3
SUMMARY OF EXPLORATION
FRANCISCAN DAMSITE

Founda- tion	Date	Location	Elevation (ft.)	Inclination (deg)	Interval (ft.)	Remarks	% Core Recovery (excl. of over- burden)
RA-1	6-6-57	Middle right abutment, on axis	1584	Vertical	76.5 Not tested, unable to seat packer.	Five feet of overburden overlies intensely fractured brown, medium- grained sandstone with minor interbedded mudstone.	23.6
LC-1	5-17-57 5-29-57	Left bank, on axis	1399	60°	152.9 Interval Tested: 35.9' Loss: .01 gpm/ft. @ 150 psi.	67 feet of graywacke sandstone over- lies 46 feet of highly fractured shale with numerous gouge zones. Beneath this is fractured, inter- bedded sandstone and black shale.	84.6
LA-1	5-31-57 6-1-57	Middle left abutment, on axis	1578	Vertical	65.6 Not tested, unable to seat packer.	18 feet of overburden overlies a sequence of interbedded, sheared, and fractured sandstone and shale.	75.3
LA-2	6-3-57 6-4-57	Left abutment, west of axis	1576	Vertical	45.2 Interval Tested: 20.2' Loss: 0.83 gpm/ft. @ 100 psi.	13 feet of overburden overlies interbedded fractured graywacke and argillite with intervals of gouge occurring frequently.	47

Middle Eel-Glenn Tunnels

The Eel-Glenn Tunnels are designed to convey the surplus flows of the Middle Eel River into the Glenn Reservoir Complex (see Plate 1). These tunnels would be at least 10 feet in diameter and in excess of 20 miles in length, and have a capacity of about 1,000 second-feet.

The proposed tunnel alignments lie in the Northern Coast Range geomorphic province and are underlain by rocks of the Central and Metamorphic belts of the Franciscan formation. The area is characterized by deep V-shaped canyons and a subparallel northwest alignment of topography and drainage, controlled by the regional trend of the Coast Range geologic structure.

Two alternative tunnel alignments were considered -- a northern and southern route as shown on Plate 7, "Geologic Map and Sections". The northern alignment inlet portal is in Black Butte River Canyon, Section 35, T23N, R11W, and the outlet portal is Thomes Creek Gorge, Section 18, T23N, R7W, a total length of 20.5 miles. The northern alignment would be used to convey water to the Paskenta and Newville elements of the Glenn Reservoir Complex. The southern alignment would have its inlet portal on Hayshed Creek, a tributary of the Middle Fork Eel and its outlet portal in Grindstone Creek Canyon. This proposed tunnel is 23.5 miles long and would divert water to the Rancheria or Millsite Reservoirs of the Glenn Reservoir Complex.

Exploration

A geologic mapping and core drilling program was undertaken in the summer and fall of 1959 to provide information relating to the feasibility of construction of the Eel-Glenn Tunnel. The geologic mapping was conducted on a regional scale in order to establish zones or areas of relative tunneling difficulty. Based on this information, the most favorable alignments were chosen.

A diamond drilling program was conducted in the Thomes-Grindstone area from June through October 1959. The object of the core drilling was to obtain information on tunneling conditions near the proposed tunnel grade.

Five core holes were drilled varying from 116 feet to 905 feet in depth. All holes were vertical with a total drilled footage of 2,534 feet.

Test Hole 1 - The first drill hole, TH-1, was located on Twin Rocks Ridge in SE 1/4 of Section 5, T22N, R10W, MDB & M. Drilling started on June 9, 1959, and was completed on August 5, 1959, with a total drilled footage of 905 feet.

Core samples were taken at intervals of about 100 feet to a depth of 778 feet and continuous samples were obtained from 770 feet to the bottom of the hole.

The core indicated that below the weathered zone the degree of jointing and fracturing diminished markedly. Near the bottom of the hole, most fractures were healed with calcite; however, it appears that a number of interconnected fractures exist in the rock even at great depth.

Fine-grained rock such as shale and siltstone exhibited intense shearing, slickenside, and clayey gouge, while coarser-grained rock was only moderately fractured at depth.

In plotting the temperature variations in the drill hole, it became evident that circulation of ground water must take place in the interval drilled. Anomalous low readings were obtained at depth and were attributed to circulation of ground water through interconnected fractures.

Test Holes 2 and 3 - Drill hole TH-2 was located in Section 2, T22N, R7W, MDB & M, on a serpentine slide just east of the serpentine-Knoxville contact. The slide material was found to be 140 feet thick, and underlain by mudstone and sandstone of the Knoxville formation. Total depth of TH-2 was 162.5 feet.

The third drill hole, TH-3, was located 300 feet west and 85 feet above TH-2. The hole was drilled to a depth of 601 feet entirely in serpentine.

Core samples were taken at selected intervals to a depth of 500 feet, with continuous core drilling from 500 feet to the bottom of the hole.

The results obtained indicated that the degree of brecciation and shearing in the serpentine does not diminish substantially below the weathered zone.

Test Hole 4 - TH-4 was located in Grindstone Canyon below Euchre Glade, in the SE 1/4 of Section 8, T22N, R8W, MDB & M. The core hole was drilled to a depth of 750 feet entirely in sandstone and shale of the Franciscan group.

Core samples were obtained for the entire depth of the hole. Drilling results indicate that several shear zones were penetrated as shown by intensely contorted, often crushed rock. In general, better core recovery was realized in portions of the hole with a high sandstone-shale ratio. The intensity of shearing and deformation was most intense in fine-grained shales with subsequent poor core recovery.

Test Hole 8 - The drill hole, TH-8, was located in the NW 1/4 of Section 7, T21N, R6W, MDB & M, near the portal of a proposed tunnel alignment. At this location the serpentine belt thins and appears to be confined to several discontinuous bodies. Surface mapping was substantiated by the drill hole, as no appreciable amount of serpentine was penetrated.

Areal Geology

The regional topography of the Northern Coast Ranges is characterized by a series of northwest-trending ranges and canyons. This trend is readily reflected in the prevalent attitude of the Franciscan rock units - predominantly northwestward strikes with variably eastward dips were mapped in the area. Local reversals of attitude due to minor folding and faulting are common and tend to obscure the regional structure.

The rocks in the area have been extensively folded, faulted, sheared, and intruded by basic and ultrabasic igneous rocks. It is generally concluded that the Franciscan rocks have undergone several periods of extensive deformation, with successive structural trends superimposed one on top of the other, giving rise to a highly disordered appearance of Franciscan rock units. The earliest period of folding and faulting

is believed to have taken place in the Cretaceous with subsequent periods of severe deformation in the Tertiary and Quaternary periods. These disturbances have deformed, compressed, and sheared Franciscan rock units and have caused development of slates and entirely recrystallized low grade schists.

For purposes of geologic mapping the area was subdivided into four lithologic units based primarily on the intensity of regional metamorphism. Rocks of highest metamorphic grade in the area were placed in the Plaskett unit which occurs near the eastern periphery of the area studied. This area of Plaskett rock types is bounded on the west by the Transitional and Franciscan units which show a progressively lower metamorphic grade. Plaskett rocks also are found at high elevations in the central portion of the area studied as shown on the geologic map, Plate 7.

The Plaskett schists and phyllites contain the same lithologic types as found in the slightly metamorphosed Franciscan to the west, and may represent a mildly metamorphosed phase of the Franciscan. Sedimentary textures are apparent even in areas of relatively intense deformation.

The boundaries between the Plaskett, the Transitional, and the Franciscan rock types are extremely complex. Gradational contacts have been observed in Grindstone Canyon where intensely crenulated quartz-sericite schist grades into slaty shale and graywacke with all intermediate stages of metamorphism present between the units. This transition takes place within a distance of 3 miles. The relationships between rocks of higher and lower metamorphic grade in a direction normal to the major drainage are not entirely understood. There is evidence of both gradational as well as thrust fault contacts.

A less prominent belt of metamorphic rocks occupies the crestral regions of Etsel and adjacent ridges. Slates and schistose sandstones are the predominant rock types. Transitional contacts with undeformed rocks were observed to the west. Several shear zones were mapped along the eastern periphery of the metamorphic belt indicating a possible fault contact.

Structure

Several major folds have been outlined in the area mapped (see Plate 7). The two metamorphic belts appear to be located in two northwest trending synclinaloriums, separated by a narrow structural high along Grindstone Creek. This interpretation is based on the sequence of rock types as well as on prevailing attitudes.

Another area of broad folding is located along Etsel Ridge. The structure in this region is only partially understood due to discontinuity of rock types, variable attitude and poor exposures.

Minor folding or wrinkling, often associated with shearing, has been observed throughout the area mapped, and tends to obscure major structure. The intensity of folding and wrinkling of the strata increases sharply from Franciscan to Plaskett units, reaching a maximum in Grindstone Canyon near the serpentine contact.

A marked reversal in the regional attitude of strata has been observed between the Plaskett and Franciscan units. The regional strike of Franciscan units is generally to the northwest with an eastward dip. Attitudes of the Plaskett schists and phyllites are much less consistent, as both northwest as well as northeast strikes are common. Bedding is not readily apparent and it was assumed that slaty cleavage in the metamorphic units is roughly parallel to the stratification. A deviation of cleavage or schistosity from actual bedding may be responsible for the apparent reversal of attitude. The reversal of strike can also be interpreted by introducing a thrust fault at the base of the Plaskett unit. The contact appears to be a thrust in the Black Butte River Canyon from Butte Creek to Logan Basin.

A number of major faults have been delineated on the basis of current mapping. Most conspicuous of these is a zone of crushed and sheared graywacke, shale, and greenstone which extends along the eastern flank of Etsel Ridge, a short distance above the Black Butte River (see Plate 7). This zone ranges from 200 to 500 feet in width. Near the Eel River Ranger Station highly sheared and contorted rock was observed over a width of some 2,000 to 3,000 feet, possibly indicating an intersection of several shear zones. The Black Butte fault zone is characterized by

highly sheared rock and clayey to silty gouge, and in many places slides have developed due to the incompetency of fault zone material. The extent of this fault was traced from a point a mile downstream from the Eel River Ranger Station to Logan's Basin on the Black Butte Reservoir, a distance of some 15 miles.

A second major fault zone is exposed on the Eel River near the mouth of Williams Creek. This zone is at least 2,000 feet wide and consists of highly sheared and contorted graywacke, shale, and greenstone. The rocks in many places are polished and squeezed into ellipsoidal or lenticular shapes. This zone when projected on strike would be expected to lie beneath and parallel to the crest of Etsel Ridge (see Plate 7).

Numerous northwest-trending shears and fault zones occur in the Grindstone and Thomes Creek Canyons where they are well exposed near the active stream channels. Many of these shear zones are up to 50 feet in width but do not seem to be continuous over more than a mile in length. Similar shear or fault zones are suspected beneath the accumulations of landslide material and slopewash above the streams and near ridge tops.

The structural relationship of the serpentine-Plaskett contact indicate faulting as well as intrusion. In several places such as in Grindstone Canyon and Lake Hollow in Thomes Canyon the contact appears to be a fault with sheared and crushed rocks on the ultra-basic belt having been moved up with relation to the Plaskett schists. In other places, however, the fault movements are not so clear and it is likely that no great displacement has occurred along a portion of the contact. The same holds true on the east edge of the ultra-basic belt which is in contact with the Knoxville formation. In some places a great deal of shearing appears along this contact, but elsewhere the contact is clearly intrusive.

Tunneling Conditions

Four general rock or geologic units were recognized. In the order of increasing cost of tunneling these are: (1) the Plaskett Unit, (2) the Transitional or transitional Franciscan, (3) unmetamorphosed Franciscan, and (4) rocks of the ultra-basic or serpentine belt. In

general, tunneling conditions tend to improve with increase in the intensity of metamorphism and subsequent increase in the degree of induration of the first three geologic units.

Each geologic unit, as a whole, has quite distinct engineering geologic properties. However, with the exception of the serpentine belt, all contacts were found to be gradational in nature. This should be kept in mind when referring to the geologic map (see Plate 7) where contacts are shown more or less as definite geologic boundaries.

Plaskett Unit. The Plaskett rocks include phyllite, schist, semi-schist, and greenstone that exhibit a considerable degree of metamorphism. In general, the rocks are hard to very hard, moderately jointed and are difficult to break, particularly normal to the foliation.

Schists and semi-schists are tough, well indurated, and moderately fractured rocks with well developed cleavage and schistosity. Locally the schist may contain up to 30 percent by volume of vein quartz. Schists and semi-schists appear to be highly desirable rocks for tunneling, as well as the massive Black Butte greenstone member and other greenstone bodies.

Phyllites are somewhat softer than schist and will break easily along cleavage planes. Some overbreak may be anticipated in Plaskett phyllites, especially when the tunnel will cut the rock obliquely to the cleavage.

Overall, the Plaskett unit should not present any extensive tunneling difficulties.

Transition Unit. Rocks of the Transition unit represent an intermediate state of metamorphism between the moderately well metamorphosed Plaskett and the Franciscan rocks. The Transition unit is composed chiefly of slate, phyllite, and slightly schistose sandstone or graywacke. Several relatively discontinuous greenstone bodies have also been mapped within this unit.

Phyllites and slates have a well developed slaty cleavage and are extensively jointed. Overbreak in these rock units is expected to be quite high. Schistose sandstone in the Transition unit is generally

moderately jointed and well indurated and often exhibits flaggy fracturing. Thick sections composed predominantly of schistose sandstone have been mapped in the Upper Grindstone area.

Transition rocks in general are less competent than the Plaskett unit, although highly competent rock is locally present.

Franciscan Group. Franciscan rocks as a whole appear to provide the least favorable tunneling conditions of the three main geologic units and exhibit the lowest degree of metamorphism. The Franciscan is represented by interbedded shales, mudstones, and graywacke with subordinate amounts of conglomerate, greenstone, and chert. Shale and mudstone are the most abundant rock types in the area. Shales are thinly bedded, often show slate-like partings, and are usually found interbedded with sandstone, with individual units rarely exceeding 2 feet. Due to their relatively incompetent nature the shales and mudstones have undergone a high degree of deformation. These units are usually intensely sheared and fractured or completely crushed.

Sandstones occur in beds of varying thickness averaging about 2 feet and rarely exceeding 20 feet in thickness. Sandstones are moderately to intensely jointed and should provide relatively desirable tunneling conditions. Other minor rock types in the Franciscan include conglomerate, greenstone, chert, and limestone. These rock types comprise about 25 percent of the whole group.

The rock conditions in the Franciscan unit can be described as very blocky and seamy to completely crushed.

Considerable squeezing may be expected locally in highly sheared incompetent shale, necessitating an invert strut or similar protection against lateral pressure.

Fault Zones. All current tunnel alignments will intersect at least one major shear zone (see Plate 7).

Fault or shear zones are recognized by intensely sheared and brecciated rock and are at times in excess of 1,000 feet in thickness. Displacements were very difficult to determine due to lack of continuity of lithologic units.

The rock within a major shear zone can be classified as highly incompetent and completely crushed. Squeezing conditions will probably prevail throughout at least one-third of the major shear zones. Closely spaced circular support will probably be required.

Large water inflows under high pressures are anticipated in intensely brecciated, sheared rock.

Serpentine Belt. Rock units of the serpentine belt will provide the least desirable tunneling conditions of the four units. The rock is intensely fractured and often completely crushed. The degree of fracturing and shearing is not expected to diminish with depth to any great extent. Numerous fractures and shears are an inherent property of serpentine because during the serpentization process an increase in volume of the entire rock body occurs through addition of water and the adjustment of the rock to internal stresses is by shear and brecciation. Competent bodies of rock have been mapped in the serpentine belt; however, they appear to be discontinuous and bounded on all sides by sheared serpentine.

As a whole the serpentine belt units were classified as completely crushed, moderately squeezing rock. Circular ribs or invert support will be required to compensate for lateral pressures where encountered. Water inflow in the serpentine will be large and under moderate to high hydrostatic pressures.

Ground Water

Annual precipitation in the crestal and flanking regions of the area averages 60 inches yearly. Large stands of timber and dense brush as well as other vegetation cover most of the area. The main streams flow perennially, but some tributaries become dry during the summer. Numerous springs were noted at various elevations. Most springs are perennial and continue to flow in the driest years even at high elevations. Mildly sulfurous waters are known from only four localities. No hot water springs were found or are known in the immediate area.

Water inflow in the tunnel should be high owing to a relatively high depth of cover and intense fracturing of the rock. Highest inflows

are expected in crushed and brecciated rock, where the water is able to move downward through interconnected fractures.

Tunneling Conditions Zones

Four zones were differentiated on the relative tunneling conditions map (see Plate 7 and Table 4). These zones are not necessarily delimited by lithologic or formational boundaries but are more closely related to engineering properties of the rocks in the general area and are projected to tunnel grade. Factors such as degree of fracturing, chemical alteration, hardness, stratification, and schistosity were used in determining the relative competency of the rock. Additional field study is required to properly evaluate the tunneling conditions at any particular point within a zone or along a definite alignment. Most favorable tunneling conditions should be encountered in Zone 1, becoming progressively less favorable in Zones 2, 3, and 4. The road load factors assigned to each of the zones are described in Department of Water Resources Bulletin No. 78, Appendix C, "Procedure for Estimating Cost of Tunnel Construction".

Recommendations

1. Additional geologic mapping is desirable to determine the geologic structure with a greater degree of accuracy. Detailed mapping along most favorable alignments should be conducted for proper evaluation of tunneling conditions.

2. Core drilling is recommended to determine whether the schists are present at tunnel grade. A favorable drill hole location would be at Oak Knoll where the Plaskett schists are suspected to occur as a thin unit.

3. A magnetometer survey is recommended to assist in determining the structure of known serpentine bodies which do not outcrop. A magnetic survey could also be used to project fault zones which are characterized by discontinuous pods of serpentine.

4. Core drilling along the northern or the Spencer-Glenn alignment. Drill holes could be located in the portal and shaft areas.

5. Detailed geologic mapping along the proposed tunnel alignment. Special emphasis should be made on mapping of shale-sandstone ratio. All mapping should be projected to tunnel grade.

6. Excavation of an exploratory adit, located to give a most representative cross-section of rock types under a considerable depth of cover.

TABLE 4

SUMMARY OF TUNNELING CONDITIONS
MIDDLE EEL-GLENN TUNNELS

Zone :	Rock types :	Rock conditions :	Rock load : :Hp in feet :	Excavation : : method :	Steel rib : : spacing :	Overbreak :	Lining :	Water :
I	Plaskett metamorphics and especially competent portions of the Transition and central belt Franciscan.	Schistose or stratified to moderately blocky and seamy.	0 to 0.3 (B + H _t)	Full face	Horseshoe ribs on 6-foot centers.	Light-primarily a-long schistosity and bedding planes.	100 percent circular concrete.	Low to moderate inflow - 95 percent dry heading.
II	Transitional unit and large portions of central belt Franciscan.	Stratified to very blocky and seamy.	0.3 to 0.7 (B + H _t)	Full face	Horseshoe steel ribs on 4-foot centers.	Moderate	100 percent circular concrete.	Moderate inflows. Intense locally. 95 percent dry heading.
III	Sheared and intensely fractured portions of central belt Franciscan.	Completely crushed.	0.7 to 1.0 (B + H _t)	Multiple drift. Full face where possible.	Horseshoe with invert struts on 4- to 2-foot centers. Circular support where rock loads are great.	Moderate to high.	100 percent circular concrete.	High water inflows. 90 percent dry heading grouting ahead may be required locally.
IV	Fault or major shear zone and rocks of the serpentine belt.	Completely crushed. Moderately squeezing.	1.0 to 2.6 (B + H _t)	Multiple drift (not applicable for small tunnels). grouting ahead of the face may be needed.	Circular support on 2-foot center heavy lagging.	High.	100 percent circular concrete.	Heavy water inflows. 50 percent wet heading.

Elk Creek Tunnel

The Elk Creek Tunnel is designed to convey the surplus flows of the Middle Eel River to English Ridge Reservoir on the Upper Eel River. The tunnel area is covered by the Eden Valley USGS quadrangle map with a scale of 1:62,500 and a contour interval of 100 feet. Access into the tunnel area is provided by several unimproved private roads and large sections of the area can be reached on foot only. The tunnel area becomes virtually inaccessible in the winter or after prolonged rain.

Four alternative tunnel alignments were investigated during the brief reconnaissance and are shown as lines A through D on Plate 8, "Tunneling Conditions Map and Sections". The geologic work is of preliminary nature and detailed geologic mapping is needed for an adequate evaluation of the tunneling conditions in this geologically complex region. Geologic mapping is greatly handicapped by heavy overburden and vegetation and by the poor accessibility of the tunnel area.

Tunneling Conditions

The proposed Elk Creek Tunnel alignments are underlain by sedimentary, igneous, and metamorphic rocks of the Central Belt Franciscan belt. Rock types mapped included sandstone, shale-mudstone, chert, greenstone, phyllite and slate, serpentine, and partially serpentinized ultrabasic rock. Minor units consist of conglomerate, glaucophane schist, and various exotic rocks associated with serpentine and major fault zones. Virtually all rock units crop out as discontinuous northwest oriented lenses and no differentiation of rock types could be attempted during reconnaissance study. Plate 8 shows belts or assemblages of rock types which as a group constitute a distinct tunneling conditions unit.

Rock Types

Sandstone. The sandstone is generally a dense, fine-grained graywacke with frequent shale interbeds. It has a characteristic greenish-gray color when fresh, weathering to a tan-brown. Tunneling conditions in the sandstone can be summarized as moderately blocky and seamy.

Shale. Shale and siltstone are thinly bedded, dark-colored rocks, usually showing slaty partings or cleavage. The degree of fracturing is most intense in thin shale lenses interbedded with more resistant rock. Outcrops of shale are poor due to deep weathering and heavy soil mantle. Fresh exposures are generally confined to active stream channels.

A thick section of shale and siltstone was mapped on the western slope of Bald Mountain. Extensive landsliding in this area reflects the relative incompetency and susceptibility to weathering of the underlying rock. Tunneling conditions in the shale will be very blocky and seamy to completely crushed.

Phyllite and Slate. Phyllite and slate represent moderately metamorphosed shale and siltstone. The effect of metamorphism was to weld the rock into a more resistant unit than the original material. The rock is generally dark and fine-grained, showing intense contortion and crenulation of the bedding. Slaty cleavage may be observed locally. Overall, the rock may be considered as schistose to moderately blocky and seamy.

Greenstone. Greenstone represents altered basic igneous rock and is usually the most resistant unit of the Franciscan group. Greenstone crops out in rounded steep sided plugs or stacks along the tunnel lines. Tunneling conditions vary from massive to moderately blocky and seamy.

Ultrabasic Rock. Several large bodies of ultrabasic igneous rock, apparently of intrusive origin, were mapped near the tunnel alignment. The rock is usually very fine-grained and dark colored and may locally be equivalent to greenstone. Portions of the rock have been sheared and serpentized. It was estimated that ultrabasic rock contains about 5 percent of serpentine.

Tunneling in the ultrabasic rock will be highly variable, ranging from moderately blocky and seamy to very blocky and seamy and completely crushed.

Serpentine. Serpentine will provide the most undesirable tunneling conditions. The rock is intensely fractured to completely crushed. The degree of fracturing and shearing will not diminish to any great extent with depth.

Serpentine may be classified as completely crushed, moderately squeezing rock.

Faulting

Based on preliminary geologic reconnaissance, at least two major faults traverse the tunnel area. The fault zones are typified by completely crushed gougy rock and often contain lenses of sheared serpentine. Springs, seeps, and landslides are common along the fault trace.

Minor faults and shears are extremely common throughout the region and the whole tunnel area appears to have suffered successive periods of very strong deformation. Detailed geologic mapping is needed to locate any concealed fault zones and to delimit areas of strong deformation.

Water

Water inflow into the proposed Elk Creek Tunnel will be moderate to high. The average rainfall in the area varies from 50 to 60 inches annually. Numerous springs and seeps were observed even at high elevations. Highest inflows will be in crushed and brecciated rock, where water can seep downward.

Tunneling Conditions Zones

The tunnel area was subdivided into four tunneling conditions zones based on the cost of tunneling as related to the rock conditions. Overall the tunneling characteristics in the area will be poor and will range from moderately blocky and seamy to very blocky and seamy to completely crushed. The tunneling zones were recognized from air photo interpretation with only limited field check. The boundaries as shown on Plate 8 should be considered as diagrammatic in part. The rock load factors assigned to the four zones are described in Department of Water

Resources Bulletin No. 78, Appendix C, "Procedure for Estimating Costs of Tunnel Construction".

Zone I. Zone I consists of sedimentary rock units of the Central Belt Franciscan which are only moderately sheared and jointed. Predominant rock types are graywacke sandstone, shale, and an unusually high concentration of thin bedded chert. It was estimated that about 10 percent of Zone I will be excavated under wet heading conditions.

Summary - Zone I

Rock Condition	: : Rock Load Hp : in feet	: : Percent : of Zone
Moderately blocky and seamy	0.35 ($B+H_t$)	75
Very blocky and seamy	0.725 ($B+H_t$)	25

Zone II. Zone II is similar geologically to Zone I but contains a higher shale-sandstone ratio and shows considerably more shearing and fracturing.

Summary - Zone II

Rock Condition	: : Rock Load Hp : in feet	: : Percent : of Zone
Very blocky and seamy	0.725 ($B+H_t$)	90
Completely crushed	1.10 ($B+H_t$)	10

About 15 percent of Zone II will be "wet heading" tunneling.

Zone III. This zone consists of sheared and fractured Franciscan sedimentary rock, intruded by serpentine and cut by numerous faults and shear zones. A detailed mapping program is necessary for a proper evaluation of the tunneling conditions within this unit. All rock units are discontinuous and present an extremely disoriented assemblage.

Summary - Zone III

Rock Condition	Rock Load Hp in feet	Percent of Zone
Very blocky and seamy	0.725 ($B+H_t$)	50
Completely crushed	1.1 ($B+H_t$)	50

About 20 percent of this zone is expected to be "wet heading" tunneling.

Zone IV. This zone covers the two major fault zones mapped in the tunnel area. The rock is completely crushed and is reduced locally to a clayey gouge with very little strength. Numerous springs and seeps along the fault trace indicate that large inflows should be expected at tunnel grade. Squeezing conditions and "running ground" can occur in completely crushed saturated rock necessitating grouting ahead of the heading and closely spaced circular steel ribs.

Summary - Zone IV

Rock Condition	Load Factor Hp in feet	Percent of Zone
Completely crushed	1.1 ($B+H_t$)	75
Moderately squeezing	2.1 ($B+H_t$)	25

Fifty percent of Zone IV is expected to be "wet heading" tunneling.

Conclusions

1. The geologic investigation of the proposed tunnel consisted primarily of aerial photo analysis with little field check and should not be considered adequate for advanced planning.
2. The proposed Elk Creek tunnel lies in an area of extreme geologic deformation and will encounter a high percentage of poor rock.
3. The tunnel will be 100 percent supported and lined.
4. Water inflows are expected to be generally high especially in sheared and fractured rock under considerable depth of cover. No hot or mineralized ground water was noted in the area.

Recommendations

1. A detailed geologic investigation is required to determine the geologic structure and tunneling conditions with a greater degree of accuracy so that the most favorable alignment can be selected.

2. An airborne magnetometer survey in areas of the tunnel underlain by serpentine is recommended. This survey should be closely coordinated with geologic mapping.

3. Later stage investigations should include trenches and drill holes along the most favorable alignment and portal areas in addition to test adits in representative rock assemblages.

Upper Etsel Damsite

Upper Etsel damsite is located on the Middle Fork Eel River, 5-1/2 miles southeast of Covelo. The site is an alternative to Spencer damsite which is located 2 air miles upstream. The USGS Covelo quadrangle, with a scale of 1:62,500 and contour interval of 100 feet, and a Department of Water Resources map, with a scale of 1:4800 and contour interval of 20 feet, provide topographic coverage of the area.

A reconnaissance geologic investigation was conducted for a 450-foot-high fill-type dam with a crest elevation of about 1,735 feet. The purpose of the investigation was to determine the foundation conditions beneath the dam and in the spillway area, and locate suitable construction materials.

Geology of the Site

The foundation rock is slate (65 percent), sandstone, and a small amount of conglomerate, all in the slightly metamorphosed Franciscan formation. The rock has been folded and strikes generally northwest, but the dip varies considerably. The slate is slightly to moderately contorted, and the sandstone is slightly schistose. Where the slate is uncontorted, it splits easily into thin, platy sheets. The folding and metamorphism which the rock has been subjected to has generally increased its competency.

The rock is lightly jointed with the joint planes generally spaced over 3 feet apart. The joint and foliation planes are tight and impervious. No faults were observed at the site and only minor shears were noted. Leakage through the foundation and abutments is not expected to be a problem. It is estimated the grout take for a cutoff will be low.

The fresh rock has adequate strength to support a dam of the desired height. In the channel, the rock is fresh and well exposed on the surface, but on the abutments it is covered by soil and is weathered to considerable depth. It is estimated that stripping of up to 30 feet of soil and weathered rock will be required on the upper part of the abutments for a dam 450-feet high. The following table gives the estimated

stripping requirements. About 75 percent of the material stripped from the abutments could be used in the fill.

Stripping Estimates

	<u>Impervious</u>	<u>Pervious</u>	<u>Rockfill</u>
Left Abutment	Averages 15 feet	Averages 10 feet	Averages 15 feet
Channel	5-10 feet of gravels.	None	5-10 feet of gravels.
Right Abutment	Averages 25 feet	Averages 15 feet	Averages 25 feet

NOTE: Right abutment contains a terrace up to 50 feet thick at elevation 1,550.

The right abutment contains two old stream terraces at elevations 1,340 and 1,550. The upper terrace has a maximum thickness of about 50 feet, but the average thickness is probably not over 20 feet. The lower terrace averages about 5 feet in thickness. Material in the terraces consists of clayey silty gravel, which appears to be semi-pervious. It should be stripped beneath the impervious zone, and also beneath any rockfill section. The stripped material can be used in the fill.

Spillway

An around-the-end type spillway could be located on the left abutment, but it would require a deep cut. Cut slopes should be about $1\frac{1}{2}$:1 in the upper 50 feet of the cut, and about 1:1 below. Foundation rock and excavated rock would be mostly slate and would be unsuitable for use in the fill because of its platy, fissile character. Consequently, a shaft-type spillway may be more suitable. The slate will require full lining and support in tunneling operations, but it should present no unusual difficulties in construction.

Construction Materials

The results of earlier surveys for construction materials for Spencer, Franciscan, and Jarbow damsites, with modifications due to

subsequent work, are included in this report since much of the material is within a reasonable haul distance of the Upper Etsel damsite. Plate 6 shows the locations of the areas, and Table 5 describes the more important features of each area.

Impervious Material. Area I-5, located along the crest of Dingman Ridge, appears to be the best source of impervious material. It is predominantly clayey silt, formed by the weathering of slates and phyllites. Below a depth of 10 to 15 feet, most of the material consists of soft, weathered rock fragments which easily break down to clayey silt. Very few rock fragments would remain intact after compaction. The material has very low permeability and moderately low shear strength. Seven auger holes show that the average thickness of usable material is over 20 feet along the ridge crest. Over 20 million cubic yards of material are available within 2 miles of the site.

Area I-4 is a stream terrace upstream of the axis, and contains about 1.5 million cubic yards of clayey, sandy gravels. The gravels are up to 12 inches in diameter, but they are unsound and break down easily under light hammer blows. It appears that the material, after compaction, would have low permeability, but it may be suitable for use as semi-pervious fill only.

Pervious and Semi-Pervious Material. Five areas containing pervious or semi-pervious material have been located and described in investigations for other damsites. They are P-1, P-2, P-3, P-4, and P-5 as shown on Plate 6 and described in Table 5.

One other source of pervious material not shown on Plate 6 occurs along the stream channel downstream from the site. It contains an estimated 200,000 cubic yards of coarse gravel per mile of channel, upstream and downstream from the dam axis. The gravels are not continuous but are concentrated in bars. The maximum thickness in the bars is estimated to be less than 20 feet, and the average thickness about 5 feet. The gravels would have to be processed for use in filters or drains since over 50 percent is larger than 4 inches in diameter. High water in the river would flood the deposits. Except for gradation, the material is suitable for use as aggregate.

Rockfill and Riprap. Areas R-1 and R-2 on Plate 6 are located within 2 miles of the dam axis and contain rock believed to be suitable for use as rockfill.

Area R-2 contains over 20 million cubic yards of greenstone. Outcrops are scarce but the rock observed is highly fractured, and it is believed this condition will extend to considerable depth. If so, the excavated rock will consist mostly of fragments smaller than about 6 inches, and will contain considerable fine material. However, the fresh rock is strong and tough, and should be suitable for use as rolled rockfill, with selected portions suitable for riprap. Some selective excavation will be necessary because of included phyllites, cherts, and local deeply weathered areas. The average stripping required to obtain suitable rock is estimated to be 30 feet.

Area R-1 contains an estimated 1.5 million cubic yards of greenstone, similar to that in R-2 but less fractured. The material is well exposed on the surface and is believed to be the best source of large rock. Required stripping will be about 5 feet.

Area R-3, located 2-1/2 miles downstream from the axis, is considered as a possible source of material for Jarbow damsite. It reportedly contains 20 million cubic yards of interbedded sandstone (75 percent) and shale (25 percent) suitable for use as rockfill or riprap.

Conclusions

1. The foundation rock has adequate strength to support a fill-type dam of the desired height of 450 feet.
2. The thin ridges on the upstream and downstream edges of the fill have adequate strength to allow the dam to be butted against them without requiring measures to increase their structural stability.
3. If the spillway is located on the left abutment, over 75 percent of the excavated material will have to be wasted. A shaft-type spillway may be more practical.
4. Diversion tunnels and outlet works can be located where most convenient.

5. Sufficient impervious material is available within 2 miles of the site.

6. Less than 4 million cubic yards of pervious material are available within 3 air miles of the site.

7. Over 20 million cubic yards of greenstone suitable for rolled rockfill are available within 2 air miles of the site. Portions of this rock will suitable for use as riprap.

Mill Creek Damsite

Mill Creek damsite is on Mill Creek approximately 6 miles southeast of the town of Covelo, Mendocino County, California. The proposed axis is in the S 1/2 of Section 23 and the N 1/2 of Section 26, T22N, R12W, MDB & M. The USGS 15 minute quadrangle, with a scale of 1:62,500 and a contour interval of 100 feet, shows the topography of the area.

A graded county road lies 1 mile west of the damsite. A private ungraded road runs from the county road to the Middle Fork Eel River and crosses the west abutment of the proposed dam.

Description of Project

Mill Creek Dam will be part of an alternative plan including a large Dos Rios Dam and Reservoir. It would be required to prevent flooding of Round Valley. Although no spillway or outlet works would be required, a tunnel would be necessary to drain the valley to a point downstream from Dos Rios Dam. The maximum water surface elevation of the proposed Dos Rios Reservoir would be 1,550 feet, requiring the height of the proposed earthfill dam on Mill Creek to be approximately 275 feet.

Geology of the Site

The damsite is underlain by the Franciscan formation of Jurassic age. These sedimentary rocks, well exposed in the channel area, consist of slaty shale with some interbeds of graywacke sandstone. The beds trend across the channel (N45-60°W) and in general dip downstream (70°NE). Overlying the Franciscan formation in the river channel are thin deposits of sand, gravel, and some talus blocks.

Three small, shallow landslides occur downstream from the dam axis on the north side of the canyon and would lie in the reservoir area. These slides are of the debris flow type, composed of soil and weathered rock fragments. They average approximately 20 feet in thickness.

The slaty shale, which comprises 80 percent of the foundation rock, is gray to black, moderately soft to moderately hard, aphanitic to

fine-grained, and contains numerous small shear zones. The shale is moderately jointed, with the joints trending approximately normal to bedding.

The sandstone, which comprises 20 percent of the foundation rock, is gray, fine-to medium-grained, and moderately hard, and occurs as interbeds varying from a few inches to 2 feet in thickness.

Right Abutment. The right abutment is a moderately steep slope of 1.75:1. The rock outcrops are excellent near the stream channel, but a thin mantle of soil covers the foundation rock on the rest of the abutment. The brush and tree coverage is slight. No terraces, landslides, or faults were observed.

Channel. The present stream channel is approximately 40 feet wide, and the flowing water was 20 feet in width. The rock outcrops are excellent along the channel section. Numerous small shear zones were observed, but no major faults were observed. The Franciscan rock is overlain by Recent alluvium that consists of sand, gravel, and some talus blocks. The stream gravels have an average thickness of 5 feet and a maximum thickness of 10 feet.

Left Abutment. The left abutment has a slope of approximately 2-1/2:1, and since it is on the north side of the mountain has developed a deeper soil mantle than that found on the right abutment. The rock outcrops are excellent near the channel, fair in the road cut, and spotty elsewhere on the abutment. The brush and tree coverage is moderate. No faults, slides, or terraces were observed.

Stripping Estimates

The following table is a summary of stripping depths measured normal to the ground surface. All stripping can be done by common excavation.

Right Abutment	Left Abutment	Channel
<u>Impervious Section</u> Varies from 10 to 15 feet of soil and weathered bedrock.	Varies from 15 to 20 feet of soil and weathered bedrock.	Averages 5 feet of gravel and 5 feet of weathered bedrock.
<u>Pervious Section</u> Averages 2 feet of soil and root zone.	Averages 5 feet of soil and root zone.	None

Construction Materials

Impervious. Older alluvium, consisting of slightly cemented pea gravel, sand, and clay, occurs along the south edge of Round Valley and seems to be of sufficient quantity and quality for the impervious borrow material (area I-6, Plate 6). This would involve a haul distance of approximately 2-1/2 miles.

Pervious. Sufficient quantities of pervious material occur upstream in the channel of Mill Creek, 1 to 3 air miles from the damsite (see Plate 6).

Riprap and Rockfill. Suitable riprap material and material of sufficient quantity and quality for a rockfill dam was not encountered during the reconnaissance of this damsite.

Aggregate. The same source as for the pervious material is proposed for the aggregate material.

Conclusions

1. Based on a limited geological reconnaissance the site appears suitable for an earthfill dam 400 feet in height.
2. Construction materials of sufficient quantity and quality are apparently available locally for an earthfill dam.

Recommendations

Investigation of the following specific items is recommended if Mill Creek Dam is considered further.

1. Location of a suitable riprap quarry site.
2. Auger drilling for impervious materials.
3. Testing of the terrace material and the stream gravels as to their suitability for borrow materials.
4. Detailed geologic mapping of the site with attention to the possible presence of major faults.
5. Diamond drilling along dam axis and spillway centerline.

Mill Creek Tunnel

The Mill Creek Tunnel is located between Mill Creek and the Middle Fork Eel River. It lies in Sections 22, 27, 33, T22N, R12W, and Section 4, T21N, R12W, MDB & M, in Mendocino County. The entire tunnel alignment is covered by the USGS 15 minute Eden Valley quadrangle, with a scale of 1:62,500 and a contour interval of 100 feet.

Access to the tunnel alignment is by private dirt road from Round Valley, near the inlet portal. This road crosses the alignment along the ridge of the mountain.

Description of Project

When the Mill Creek Dam is constructed it will block the natural drainage of Round Valley. A drainage tunnel will be needed to carry the flow of Mill Creek to the Middle Fork Eel River to a point below either Dos Rios or Jarbow Damsites.

The approximate inlet and outlet elevations used during this reconnaissance were 1,300 and 1,100 feet, respectively. The length of the alignment is approximately 2.9 miles, trending S27°W from inlet to outlet. The maximum depth of cover will be 900 feet. (NOTE: This alignment was originally studied in connection with the Jarbow Dam and Reservoir. An alignment located farther west will be required for the Dos Rios project.)

Tunneling Conditions

The entire Mill Creek drainage tunnel lies in rocks of the Franciscan group. The two major rock units are sandstone and shale. The rocks occurring in minor quantities are chert, conglomerate, and actinolite schist. No serpentine or related ultrabasic rock was observed along the proposed tunnel route.

The prevailing attitude of the beds is east-west; the strike varies from N60°E to N75°W, with steep dips both to the north and south.

Rock Types

Sandstone (60 percent). The sandstone is gray, fine- to medium-grained, and moderately hard, and generally found as massive, jointed outcrops. The sandstone also occurs as thin interbeds in the shale unit.

The tunneling conditions in this unit can be summarized as moderately blocky and seamy.

Shale (40 percent). The shale is gray to black, moderately soft to moderately hard, and aphanitic to fine-grained, contains numerous small shear zones, and is moderately jointed. The shale, being the less resistant rock, does not crop out as frequently as the sandstone unit. The tunneling conditions of the shale are 90 percent very blocky and seamy and 10 percent crushed.

Portal Locations

The inlet portal would be located in Section 22, T22N, R12W, MDB & M, 1,000 feet south of Mill Creek, up a small canyon where a 50-foot "face" could be located. This would require the excavation of an approach channel to the portal.

The outlet portal would be located in N 1/4 of Section 4, T21N, R12W, MDB & M, to the east of Round Mountain in a landslide area. This landslide is approximately 40 feet thick.

Water and Gas

Water inflow into the proposed Mill Creek drainage tunnel should be slight to moderate. The highest inflows should be in the crushed shale beds.

No evidence of thermal water or gas was found in the area studied.

Conclusions

1. The tunneling conditions along the alignment should be 60 percent moderately blocky and seamy, 36 percent very blocky and seamy, and 4 percent crushed.
2. The proposed tunnel should be 100 percent supported and lined.
3. The water inflow into the tunnel will be slight to moderate.
4. No evidence of gas or thermal water was found.

Recommendations

A detailed geologic investigation to determine the geologic structure and tunneling conditions with a greater degree of accuracy is required. Geologic mapping should be extended to the west to cover the alignment for drainage to a point below Dos Rios Dam.

Upper Mina Damsite

Upper Mina damsite is on the North Fork Eel River in Trinity County. The axis of the site is approximately 600 feet downstream from the confluence of the North Fork Eel River and Hulls Creek, and lies in Sections 21, 28, and 34, T5S, R8E, HB & M. The USGS 15 minute Kettenpom quadrangle, at a scale of 1:62,500 and a contour interval of 100 feet, shows the topography of the area.

The damsite is accessible by a well maintained dirt road extending northeast from Summit Valley. The closest point of approach of this road to the site is at the confluence of Hulls Creek and the North Fork Eel River.

Description of Project

The Upper Mina Reservoir would provide for diversion of North Fork Eel River waters to the Middle Fork Eel via Hulls Creek Tunnel. The maximum height of dam considered at the Upper Mina site is about 400 feet.

Geology of the Site

The damsite is underlain by sandstone, shale, and greenstone, all of the Franciscan formation. The sandstone and shale occur in discontinuous beds and lenses, and the greenstone usually occurs in pod-shaped bodies. The general strike of the beds is about N20°W and the beds dip steeply to the east. Landslides are present at the site with most of them occurring on the right abutment. The slides are believed to be relatively shallow, probably about 30 feet thick, and to affect only the soil and colluvium on top of the bedrock.

Right Abutment. Outcrops are scarce on the right abutment, except near the channel. The outcrops that are present on the abutment and in the channel indicate that the abutment is underlain by sandstone and some shale. The sandstone is hard, has good strength, and is moderately jointed. The shale is soft and moderately to intensely fractured and jointed.

Part of the right abutment contains landslide areas, which are believed to be shallow but which would have to be removed from the impervious and rockfill sections of the dam. Further investigation is needed to determine the suitability of this material for impervious or semi-pervious fill.

The slope of the abutment is moderately even, and averages about 2-1/4:1.

Channel. Bedrock is well exposed in the channel, although it is partially concealed beneath river gravels and talus blocks. The bedrock in the channel is mainly sandstone, with moderate amounts of slaty shale and greenstone. The rocks are fresh, and hard except for the shale, and would provide a suitable foundation for a rock- or earthfill dam.

Along the axis, the channel is about 150 feet in width. It contains sand and gravels to an average depth of about 5 feet. The gravels (25 percent of plus 8 inch size) are considerably deeper in local potholes. Also present in the channel are large blocks of greenstone and sandstone up to 8 feet in diameter.

Several shears were noted in the channel downstream from the axis, but none were observed at the site.

Left Abutment. Outcrops on the left abutment are scarce except for the portion near the channel. The abutment is underlain by sandstone, some shale, and probably some greenstone. The sandstone is hard, and is moderately jointed. The shale is soft and highly fractured, and in places shows shearing.

Some sliding is present on the abutment, but it is minor in extent and is probably shallow. All the slide material would have to be removed from the rockfill and impervious sections, but part of it could be salvaged for use as impervious or semi-pervious fill.

The slope is uneven and averages about 2-1/4:1 up to elevation 1,800 feet.

Stripping Estimates

The following stripping estimates are given for a rockfill dam 400 feet in height.

<u>Right Abutment</u>	<u>Left Abutment</u>	<u>Channel</u>
<u>Impervious</u> Varies from 10 to 35 feet. Averages about 25 feet. Remove all soil, colluvium, and slide material and a few feet of weathered bedrock.	Varies from 5 to 25 feet. Averages about 15 feet. Remove all soil, colluvium, and minor slide material and a few feet of weathered bedrock.	Averages 5 feet of sand and gravel. Also remove large blocks of talus up to 8 feet in diameter. Only minor shaping of bedrock.
<u>Rockfill</u> Averages 20 to 25 feet. Remove all overlying material to bedrock.	Averages about 15 feet. Remove all overlying material to bedrock.	Probably remove large talus blocks.

Essentially all of the stripping could be accomplished by common excavation methods.

Spillway

The best place for a spillway appears to be through a narrow ridge on the left abutment. The top of the ridge is at an elevation of about 1,815 feet, and a cut approximately 165 feet deep would be required for the spillway. Most of this cut would probably be in sandstone, some of which is probably suitable for use as rockfill.

The spillway should be lined from the crest down to at least elevation 1,550 feet. About 20 percent of the conveyance channel would require lining. The reentrance point would be about 500 feet from the toe of the dam. The slope of the spillway cut should be about 3:1 in the zone above the fresh bedrock (approximately the top 35 feet); then the slopes could be gradually steepened to about 1-1/2:1 or steeper.

The only other feasible type of spillway at this site would be a glory hole. An around-the-end type is probably not practical due to unstable slopes.

Construction Materials

Impervious. The landslide material in the vicinity of the dam-site is the only available source of impervious fill. The landslides commonly occur on slopes where sheared shales predominate and contain varying percentages of sheared shale, residual soil, and sandstone fragments. Because of its gradational characteristic, selective excavation is anticipated. The landslide material may be suitable for use as impervious fill. Exploration and testing is needed to evaluate the soil properties of the landslide material.

Pervious. There appears to be no large source of pervious material within a reasonable haul distance of the site. There are some small deposits of stream gravel in the river channel.

Rockfill and Riprap. Only one potential area for rockfill or riprap was located. It is 2.5 miles upstream from the site, on the North Fork Eel River. The rock is a hard, moderately jointed greenstone. No estimate of the amount of rock in this area was made, but the amount is probably insufficient to supply all the requirements of the dam. It is believed that some of the sandstone removed from the spillway cut can be used for rockfill. Sufficient rock of suitable quality is probably available within 4 miles of the site.

Aggregate. The greenstone that occurs as scattered outcrops in the damsite area is the most likely source of concrete aggregate. It would be necessary to crush and process the greenstone.

Stream gravels are not present in sufficient quantities to be considered for a source of aggregate.

Conclusions

1. The foundation of the damsite appears suitable for an earth- or rockfill dam to the proposed height of 400 feet.

2. Construction materials for the dam will be relatively costly as several quarries must be developed for rockfill, the landslide material is the only available source of impervious fill, and the greenstone must be crushed and processed for aggregate.

3. The best spillway appears to be an overpour type located on the left abutment. The second choice would be a glory hole type.

4. Landslides will be common in the reservoir area.

5. Tunneling conditions for diversion and outlet will be moderately good. The tunnels would have to be 100 percent supported.

Recommendations

Investigation of the following specific items will be necessary if Mina damsite is further considered.

1. Location of suitable rockfill quarry sites.

2. Auger drilling for impervious materials.

3. Testing of landslide debris for use as impervious material, with special emphasis on strength characteristics.

4. Detailed geologic mapping of the site with attention to extent of landslides.

5. Dozer trenches to expose depth of landslides on abutments.

6. Diamond drilling along dam axis and spillway centerline.

7. Investigation of faulting at the damsite and slides in the reservoir area.

Mina Tunnel

The proposed Mina Tunnel alignment is located in T25, 24, and 23N, R12W, MDB & M, Mendocino County, California. The entire tunnel alignment is covered by the USGS 15 minute Covelo quadrangle, with a scale of 1:62,500 and a contour interval of 100 feet.

Access is via a county-maintained dirt road which runs to the west of the proposed alignment, and a number of private ranch roads which branch out from the main road. In the winter or after prolonged rain all roads may become impassable due to slides and washouts.

Description of Project

The tunnel alignment connects the Upper Mina Reservoir in Hulls Creek with Spencer Reservoir in Williams Valley. The approximate inlet and outlet elevations used during this brief reconnaissance were 1,600 and 1,525 feet, respectively. The length of the alignment is 9.2 miles, trending S18°E from inlet to outlet.

The maximum depth of cover which would be encountered under Buck Mountain is approximately 2,600 feet.

Tunneling Conditions

The entire Mina Tunnel alignment lies in rock units of the Franciscan group. The group consists of a rather disordered assemblage of sedimentary and igneous rocks. Individual rock units tend to be discontinuous pod-shaped bodies of limited areal extent. The prevailing attitudes of the beds varied from N-S to N60°W, generally dipping to the east.

Geologic mapping was complicated by deep weathering and extensive landslides. Reliable rock exposures could be found only in the bottoms of canyons.

Rock Types

Three major rock units were differentiated in the course of reconnaissance mapping. Listed in the order of relative abundance they are sandstone (65 percent), shale (20 percent), and greenstone (15 percent). Chert and conglomerate are present but constitute less than 2 percent of the total rock. No serpentine or related ultrabasic rock was observed.

Sandstone. The sandstone is a fine-grained, dense rock, green to gray on a fresh surface. Bedding is usually difficult to recognize. In the area studied sandstone contained numerous thin shale interbeds and was moderately fractured or jointed. Tunneling conditions in this unit can be summarized as moderately blocky and seamy.

Shale. This unit includes shale, slaty shale, and siltstone. Due to their relative incompetency and deep weathering, the shale does not crop out as frequently as the more resistant sandstone and greenstone. The shale has a characteristic black color. This rock unit generally exhibits the most intense fracturing and shearing. Deformation is most pronounced in interbeds or lenses of shale confined between more resistant rock. Several shear zones, 40 to 50 feet wide, with clayey gouge, were observed in shale near the tunnel line. The extent of these shears could not be determined due to poor exposures, but they are expected to be confined to the soft, incompetent shale lenses. Tunneling conditions in shale can be summarized as very blocky and seamy to completely crushed locally.

Greenstone. The greenstone apparently represents partially altered basic extrusive. The rock has a dark green color when fresh, weathering to a reddish brown. It is the most resistant rock unit found along the tunnel alignment, and crops out in prominent cliffs and ridges.

Tunneling conditions of the greenstone will be massive and moderately jointed.

Portal Locations

Inlet. The inlet portal would be located in hard, moderately jointed sandstone. Very little excavation would be necessary to establish a 50-foot "face".

Outlet. Two alternate outlet portals were considered during this geologic reconnaissance.

1. The original portal is located below Panther Rock. No outcrops were found in the immediate portal area. Float rock and colluvium indicates a sandstone bedrock. Considerable excavation would be required in order to establish a 50-foot ledge.

2. An alternate alignment, which shortens the tunnel length by 1.2 miles, would place the portal just southwest of Coyote Rock in the channel of Tank Creek, Section 9, T23N, R12W, MDB & M. For this alignment a cut with a maximum depth of 100 feet and a length of 1.2 miles is required. It was estimated that 20 to 25 percent of the excavation will be in hardrock, primarily near the tunnel portal. The remainder of the excavation would be in silty gravel and stream alluvium. The average depth of the excavation was estimated to be 40 feet.

Water and Gas

Moderate to high ground water inflow is expected in the tunnel. The area receives an average annual rainfall of 50 to 60 inches. Maximum inflow would be expected in sheared rock, where water can percolate downward through interconnected fractures.

No evidence of gas or hot springs was found in the area studied.

Conclusions

1. The tunneling conditions along the alignment should be 65 percent moderately blocky and seamy, 15 percent massive and moderately jointed, 15 percent very blocky and seamy, and 5 percent crushed.
2. The proposed tunnel should be 100 percent supported and lined.
3. Water inflow into the tunnel is expected to be moderate. Locally high inflows are expected in sheared and fractured rock.
4. No evidence of gas or thermal water was found.

Recommendations

1. A detailed investigation to determine the geologic structure and tunneling conditions with a greater degree of accuracy.
2. Further study to determine the relative desirability of the alternate tunnel alignment and channel excavation for the outlet portal as compared to the original tunnel route.

TABLE 5

CONSTRUCTION MATERIALS TABULATION
MIDDLE FORK EEL PROJECTS

Area :	Probable Use :	Stripping Required :	Usable Volume :	Remarks :
I-1	Impervious	1 foot organic silt.	3 million cubic yards.	1) Investigated with 10 auger holes. 2) Mostly silty clay. 3) Best source impervious for Franciscan damsite.
I-2	Impervious	Very slight vegetation. 1 foot organic material.	1.8 million cubic yards.	1) Considered for Franciscan damsite. 2) Investigated with auger holes.
I-3	Impervious	Slight vegetation. 1 foot organic material.	8 million cubic yards.	1) Impervious source for Spencer damsite 2) Consists of slopewash and colluvium.
I-4	Impervious or semi-pervious.	Slight to moderate vegetation. 1 foot organic soil and root zone.	1-1/2 million cubic yards	1) River terrace. 2) Clayey sandy gravels.
I-5	Impervious	Moderate, some heavy vegetation. 1 foot organic soil and root zone.	Over 20 million cubic yards within 2 miles.	1) Closest source of impervious. 2) Usable depth is at least 20 feet. 3) Consists of weathered slate and phyllite which break down to clayey silt. 4) Investigated with 7 auger holes.
I-6	Impervious, possibly semi-pervious.	Light vegetation. 1 foot organic soil and root zone.	Over 20 million cubic yards.	1) Material is stratified - some is high strength and semi-pervious - other portions low strength and impervious.

TABLE 5 (Cont.)

Area :	Probable Use :	Stripping Required :	Usable Volume :	Remarks :
P-1 and P-2	Pervious, aggregate.	1 foot.	3 million cubic yards.	1) Planned for Franciscan damsite. 2) Contains lenses of fine materials.
P-3 and P-4	Pervious or aggregate.	1 foot or less. Slight brush.	1.1 million cubic yards.	1) Portion of this may be used for Franciscan damsite.
P-5	Pervious	1 foot including grass and roots. Very slight brush.	1.6 million cubic yards.	1) Average depth about 2.5 yards. 2) Investigated with 6 auger holes. 3) Becomes very coarse with depth.
R-1	Riprap	5 feet. Moderate brush.	1.5 million cubic yards.	1) Rock is greenstone. 2) Best source of large rock.
R-2	Rolled rockfill, selected portions riprap.	Estimated average of 30 feet. Heavy brush.	Over 20 million cubic yards.	1) Greenstone - highly fractured on surface - Estimate most of blasted rock would be smaller than 6 inches. Probably high amount of fine materials.
R-3	Rolled rockfill.	20 feet. Heavy brush.	Over 20 million cubic yards.	1) Sandstone (75 percent) and shale (25 percent). Considered for Jarbow damsite.

NOTE: (1) All volumes are bank measures.
(2) See Plate 6 for location of areas.

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TABLE 6 (continued)

Location number	Site name	Stream	Foundation conditions	Strippling	Spillway	Diversion tunnel	Construction materials	Seismic city	Feasible structures	Special problems
WP 1/1, Sec. 4, Box 20, Rte. 4, MORMA	Jarbow River	Middle Bel River	The site is underlain by dark, to medium gray, calc. sandstone, thin to medium grained, massively bedded sandstone and slaty shale. Steep slopes are broken by benches. Bedding strikes across the channel and is moderately jointed normal to the bedding.	Estimated for a 240' rockfill dam. Right Abutment -- ImperVIOUS section: 10' soil and weathered rock. Left Abutment -- 5' soil and root zone. Gravity dam: 20'.	A spillway is recommended around the end of the right abutment. It will require a 50 to 100 cut in rockfill. Sandstone material may be salvaged for rockfill or riprap.	A diversion tunnel is recommended through the right abutment.	1. Valley fill, bedded material at Jarbow Valley within 3 airline miles. P-Sand and gravel in the Middle Bel channel and stream terraces within 3 airline miles. IP & RH sandstone can be quarried near the site. Sandstone, greenstone near site.	Low to moderate	Feasible dam of moderate height.	1. Numerous slides are present in the reservoir area. 2. A structure higher than 240' will inundate Round Valley unless a structure is constructed across Mill Creek.
			Right Abutment -- Bedrock outcrops for about 300' above the channel. Minor faulting may be present. Channel Section -- The channel contains an average width of 300' of sands and gravels to an average depth of 15'. Left Abutment -- Bedrock outcrops frequently. A small bench is located about 30' above the channel.	Channel Section -- ImperVIOUS section: 5' weathered and broken rock. Pervious section: none. Gravity dam: 20'.						
				Left Abutment -- 15' soil cover, talus and rock. Pervious section: 5' soil and root zone. Gravity dam: 25'.						

CHAPTER III. GLENN RESERVOIR COMPLEX

The proposed Glenn Reservoir Complex is located on the western edge of the Sacramento Valley, in Glenn and Tehama Counties, as shown on Plate 1. The area was investigated to determine its suitability for use as a large storage reservoir for water diverted from the North Coastal area into the Sacramento Valley. The Complex would include three units: Paskenta Reservoir on Thomes Creek, Newville Reservoir on North Fork Stony Creek, and Rancheria Reservoir on Stony Creek. The topography is such that the units could be constructed simultaneously, or individually as they are needed and later combined into one large reservoir with a storage capacity of about 9 million acre-feet. The reservoir would be about 30 miles long in a north-south direction, and about 3 miles wide.

The major structures required for the development of the Complex are: Paskenta Dam on Thomes Creek, Newville Dam on North Fork Stony Creek, and either Rancheria or Millsite (Julian Rocks) Dam on Stony Creek. Also, Chrome Dike would be required if Newville and Rancheria Reservoirs were not developed simultaneously and if the water surface elevation in either reservoir exceeded about 930 feet. Geologic investigations were made for each of these structures, and a construction materials survey was made for all of the structures associated with the Complex. In addition, a geologic study was conducted to evaluate the structural stability and leakage potential of a thin hogback ridge (Rocky Ridge) which would form about 8 miles of the east rim of Newville Reservoir. Results of geologic investigations for each of the aforementioned features are discussed in this Chapter. Plates 9 to 17 illustrate the geologic conditions for project features described.

Paskenta Damsite

Paskenta damsite is located on Thomes Creek in T23N, R6W, Section 6, MDB & M, Tehama County. The axis is located approximately 2 miles upstream from the town of Paskenta on the west side of the Sacramento Valley. Access is by paved road from Corning to Paskenta and then by dirt and gravel roads to a topographic saddle located four-tenths mile southwest of the site.

Purpose and Scope

Investigations conducted at and near Paskenta damsite were to evaluate foundation conditions and locate and sample construction materials. Geologic studies were made including mapping the various foundation materials at the site and borrow areas within and adjacent to the reservoir area. Exploration and sampling of borrow materials was conducted during several months in 1960. No foundation exploration at the site was undertaken by the Department of Water Resources. However, the U. S. Bureau of Reclamation in 1946 drilled a number of diamond drill holes along the axis. This data has been used extensively in making interpretations on subsurface conditions.

Description of Project

A zoned earthfill dam with maximum height of 230 feet has been proposed for Paskenta damsite. Lower heights have also been considered at 185 feet and 135 feet. Reservoir capacity for a dam 185 feet in height (elevation 975) would be 70,000 acre-feet. Outlet works would be formed by construction of a cut and cover conduit along the base of the right abutment. A spillway for a dam of any height would be constructed on the left abutment.

Previous Investigations and Reports

The earliest known investigation of this site was by the U. S. Bureau of Reclamation in 1946. Their work consisted of drilling and water testing eight exploration holes, mapping of the site, and a reconnaissance of possible borrow areas.

In 1959 the Department of Water Resources drilled a deep diamond drill hole in the saddle southwest of the site to explore for rock-fill and riprap materials. In 1960 the Department conducted an extensive drilling and sampling program to obtain information on construction materials within and near the reservoir. A preliminary office report was written on this project. Since that time no further work has been accomplished.

General Geology

The geologic formations at and adjacent to Paskenta damsite include sedimentary rocks of lower Cretaceous, Tertiary, and Quaternary ages. The lower Cretaceous rocks consisting of sandstone, mudstone, and conglomerate are the principal rock units at the site and in the reservoir area. East of the site these rocks are overlain by semi-consolidated sediments of the Tehama formation. Quaternary deposits are represented by stream gravels and terrace deposits largely located in the reservoir area.

The lower Cretaceous rocks consist of an alternating series of conglomerates, sandstones, mudstone, and pebbly mudstone in nearly vertical beds striking at right angles to the axis of the dam or nearly parallel to Thomas Creek. The more resistant units, mainly the conglomerates, form the high northeast-trending ridges north and south of the site. The most prominent ridge, Williams Butte, is formed by a thick conglomerate bed or beds located south of the site. These conglomerate beds in Williams Butte are proposed as a source of rockfill materials.

The Tehama formation of upper Pliocene age overlies Cretaceous rocks several miles east of the site. These sediments have no importance in the investigation of this site except as an alternate source of impervious construction materials. The Tehama formation consists of various mixtures of clay, gravel, silt, and sand.

Within the reservoir area are gravelly terrace deposits generally overlain by finer grained slopewash materials. The deposits are generally thin and are underlain by Cretaceous age shale bedrock. A major portion of the construction materials would be supplied from these deposits.

Geology of the Site

Paskenta damsite has been formed where Thomes Creek has cut downward along the relatively less resistant beds sandwiched between two resistant conglomerate and sandstone beds. The foundation rock occurs in stratified beds which have nearly vertical or very high angle dips of 70° to 80° . The areal distribution of the various rock types is shown on Plate 9.

The greater portion of the site is a massive or thickly bedded, fine to medium-grained sandstone. Thickness of this principal unit is over 1,100 feet from just above the left abutment to south of the channel. This unit includes a few mudstone and conglomerate interbeds. The remainder of the site would be underlain by a thick mudstone unit extending from the sandstone unit at the base of the right abutment to above the right abutment. This rock is firm and moderately hard on a freshly exposed surface, but air slacks rapidly when exposed.

Several minor faults and shears occur within the foundation area. The largest fault, a high-angle strike-slip fault, occurs in the channel section but is largely obscured by stream gravels. Actual displacement along the fault is not known since movement has been nearly parallel with bedding, and no offsetting of beds has occurred. This fault does not seem to be a serious defect of the foundation.

Exploration

No foundation exploration has been conducted by the Department of Water Resources. The U. S. Bureau of Reclamation in 1946 drilled eight exploration holes having a total footage of 612 feet. Three holes were drilled on the right abutment and three holes on the left abutment. Another hole was drilled outside the foundation area near the downstream toe and another in the saddle north of the site where the Bureau of Reclamation proposed a spillway.

Foundation Conditions

Right Abutment. The right abutment has a fairly uniform slope of about 60 to 70 percent. Very little bedrock is exposed due to a

moderately heavy cover of soil. The principal rock type on this abutment is a mudstone. Sandstone occurs only on the lower downstream section.

The three diamond drill holes on this abutment were all drilled in the mudstone unit at the location shown on Plate 9. DH-3 was drilled at an angle of 45° to a depth of 100.2 feet. The log of the hole showed soil and weathered rock to a depth of 14.4 feet and fresh mudstone below. At a depth of 90 to 95 feet a fault zone is indicated. DH-8, a vertical hole to 35 feet, encountered soil and strongly weathered mudstone to a depth of 11 feet and fresh and partially weathered mudstone and sandstone to 35 feet. The log of DH-9, an angle hole drilled to 101 feet, recorded an overburden of soil and weathered sandstone to a depth of 12 feet. Water tests data showed water losses to range from 0 to 20 gpm at pressures from 0 to 160 psi.

Stripping will consist of about 10 to 12 feet of soil and strongly weathered rock beneath the impervious section. This will expose slightly weathered but sound rock suitable for placing fill. An additional 10 feet in firm rock would suffice for a core trench. In mudstone the rock can be ripped but light blasting may be necessary in sandstone for core trench excavation.

Channel Section. The channel section is about 150 feet wide. It is filled in the central portion with an estimated 5 feet of sand and gravel but bedrock is well exposed on both sides of Thomas Creek. Bedrock is largely sandstone with minor interbeds of shale and mudstone. A possible fault occurs along the length of the channel but sands and gravels obscure most of the fault zone. No holes were drilled in the channel section to determine the physical nature of the rock. Judging from surface exposures, the rock has not been greatly disrupted by faulting. Several minor shears and crumpling of incompetent shale and fracturing of sandstone has occurred. Special cleaning out of highly sheared rock along the fault and additional grouting may be necessary.

Stripping in the channel section beneath the entire fill will consist of removal of about 5 feet of sand and gravel in the active channel section and shaping of bedrock. A core trench, if used, would be excavated in hard but fractured sandstone requiring light blasting.

Left Abutment. The left abutment has a uniform configuration cut by a few minor ravines and covered by a light growth of scrub oak. At the base of the abutment a low bluff, about 25 feet high, occurs. The bench above this bluff is mantled by old terrace gravels and slopes upward about 10 percent. The remainder of the abutment is concave in shape with slopes gradually increasing to a maximum of 45 percent high on the abutment.

Rock on this abutment is massive to thickly bedded, hard sandstone with minor interbeds of mudstone and conglomerate. The rock is overlain at several levels by 4 to 12 feet of old terrace gravels.

Diamond drill holes, DH-5 and 6A, were drilled along the axis at the lower and upper portions respectively. DH-5, a vertical hole to a depth of 60 feet, encountered soil and weathered conglomerate to a depth of 12.3 feet and fresh hard conglomerate below. DH-6A was an angle hole drilled to a depth of 75 feet. The upper 8 to 10 feet were recorded as soil and partially weathered mudstone. Fresh mudstone and sandstone in alternating layers were cored to 75 feet.

DH-4 and DH-6 were drilled near the upstream and downstream toes, respectively. DH-4, a vertical hole, was similar to other holes in depth of weathered rock. About 12 feet of weathered, pebbly mudstone and soil overlies fresh conglomerate and fractured clay stone. DH-6, a vertical hole located outside the foundation area, recorded the thickest amount of overburden--about 25 feet of slopewash and weathered conglomerate.

Water pressure tests indicate that generally the rock is fairly tight. The maximum loss was in hole 6A, 25 gpm at a pressure of 160 psi. It is anticipated that only a small to moderate amount of grout will be accepted at depths up to 50 feet.

Stripping will be similar to the right abutment. Removal of about 10 to 12 feet of soil and weathered rock will expose suitable rock for placing fill. A shallow cutoff of 5 to 10 feet, if required, would be in sandstone (requiring light blasting) and some mudstone.

Spillway. The proposed spillway location is on the left abutment. At the proposed crest elevation of 930 feet, spillway cuts would probably be mainly in sandstone with some shale standing in nearly vertical beds. Depth to relatively fresh and sound rock would be about 15 feet at this elevation. DH-6A was drilled along the axis at an elevation of 1,009 feet and at a 45° angle into the abutment. The log of the hole records soil and firm, partially weathered mudstone to 19 feet (measured approximately normal to the surface) and fresh mudstone and sandstone to 75 feet. A water pressure test at 10 to 20 feet recorded only 3 gpm loss at 160 psi indicating that the rock at 10 feet is probably sound and very little fractured. Cut slopes above the spillway excavation should be stable at $3/4:1$ in massive sandstone and at $1:1$ in more shaley zones. Due to the property of the mudstone to air slack, berms should be provided.

The spillway chute excavation will be largely in sandstone and possibly some mudstone interbeds. Cut slopes should be at $1:1$ in the weathered sandstone. The terminal flip bucket structure may require as much as 25 feet of excavation to place it on firm rock. DH-6 recorded 20 feet of slopewash and 5 feet of decomposed conglomerate at the terminal location. Hard, fresh sandstone and conglomerate was found at a depth of 25 feet (normal to the surface).

Outlet Works. Outlet works would consist of a cut and cover conduit located at the base of the right abutment. This conduit will serve for both diversion during construction and for installation of permanent outlet works. This structure will be founded on firm rock for its entire length. The intake structure would be founded on mudstone. This structure should be away from the steep mudstone shale cliffs which may not be entirely stable. The outlet structure would be located in firm, hard sandstone.

Reservoir Area

Rock types in the reservoir area are predominantly mudstone and some sandstone of the Knoxville formation. The reservoir will not be subject to leakage. Slides will not be a problem since these rocks are

not deeply weathered. Silting is not expected to be a problem except in the upper part of the reservoir where Thomes Creek discharges from its canyon and enters the reservoir.

Construction Materials

The information presented in this report is the result of a borrow investigation conducted in 1960 by the Department of Water Resources. The investigation included the drilling of 62 auger holes and sampling and field mapping of potential sources of construction material. The auger holes were drilled in materials proposed as impervious and semi-pervious fill ranging from silty clays to gravelly clayey silts. Soil tests, consisting of mechanical analyses, specific gravity, and Atterberg Limits, were conducted on 30 samples.

The active stream channel of Thomes Creek is the proposed source of pervious fill. Additional exploration of these materials is needed. Rockfill and riprap can be produced from the Cretaceous conglomerate and sandstone which makes up the resistant ridges and topographic knobs near the damsite.

The only previous borrow exploration in this area is contained in a 1946 report by the U. S. Bureau of Reclamation entitled "Appendix, Geology of Dam and Reservoir Sites - Sacramento River Tributary Plan". This Bureau of Reclamation report contains a brief description of borrow areas and includes a map showing their locations. No sampling or exploration was performed as part of their studies. Location of all borrow areas studied is shown on Plate 10.

Impervious and Semi-Pervious Borrow. Two types of materials occur in the terraced areas along Thomes Creek. These are referred to in this report as types I and II materials.

Type I material occurs as slopewash or more explicitly as weathered and transported mudstone, sandstone, and conglomerate. In the area studied these deposits are predominantly derived from mudstone which accounts for their fine-grained nature. A typical cross-section in the areas studied is wedge-shaped with the thin portion of the wedge occurring near the creek or drainage system. The material varies from

clayey silt to silty clay and is occasionally gravelly due to weathered conglomerate contributing to the slopewash.

Type II material occurs as terrace deposits adjacent to the channel of Thomes Creek and generally beneath the fine-grained Type I materials. These deposits are both old stream channels and floodplain deposits. They contain primarily semi-pervious and impervious material; however, in some areas stream action may have washed these materials sufficiently to produce pervious material. For purposes of this report, the type II materials are considered as semi-pervious. Sampling of these materials in auger holes was not possible because of the high percentage of cobbles.

These deposits consist primarily of poorly graded silty gravels and gravelly to sandy clays with minor clayey gravels. A critical feature of the major portion of the silty gravel deposits is their "skip-graded" nature. That is, they contain a high percentage (20 to 40 percent) of cobbles and boulders which must be removed prior to their use as fill. If this type is processed the larger sizes can be used as rockfill material.

The Tehama formation located east of Paskenta damsite is typically a clayey, sandy gravel deposited as floodplain and stream channel material. Fine-grained members, consisting of both silts and clays, are present as lenticular bodies. The closest Tehama gravels are located about 2 miles from the site at about elevation 1,250. Unlimited quantities of impervious construction materials could be obtained from this alternate source if needed.

Pervious Borrow. The proposed borrow areas for this type of material are located in the channel both up- and downstream from the site. Due to their greater individual size and uniformity the downstream deposits are probably the most suitable for use as pervious borrow. The only sample tested from these areas was from AH-10. Although this sample was a sandy gravel, these downstream deposits probably range from silty sands to sandy gravel. As in the case of the terrace deposits, the channel gravels contain oversize cobbles and boulders which must be removed prior to use as pervious fill material.

Rockfill and Riprap Sources. Preliminary tests including several quarry test shots conducted during 1959 indicate that the Cretaceous conglomerate and sandstone found in the area will make suitable rockfill or riprap material. The test blasting performed on the west end of Williams Butte encountered only a small amount of fresh and unweathered rock. However, the condition of this rock and the core from a diamond drill hole indicate the material to be extremely strong, and below a depth of 20 to 30 feet to be sufficiently free of closely spaced joints and fractures to yield the sizes desired for rockfill or riprap. The 20 to 30 foot zone mentioned above consists primarily of weathered conglomerate. The material from this weathered zone contains approximately 30 percent fines due to normal weathering processes. The remainder, although weathered, appears to be suitable for rockfill material also.

Conclusions and Recommendations

1. The foundation is suitable for an earthfill dam of the height proposed.
2. The foundation rocks are essentially impervious, but since the bedding parallels the stream channel, an adequate grout curtain should be provided to intercept seepage along bedding planes.
3. Further exploration by diamond drilling is required especially in the channel section to determine rock conditions beneath the channel gravels.
4. The strength and bearing capacity of the mudstones should be determined by laboratory tests.
5. Construction materials in the reservoir should be further tested for strength and permeability. Further exploration of quarry areas is required and should include a test quarry operation.

Newville Damsite

Newville damsite is located on North Fork Stony Creek, 20 miles west of Orland in T22N, R6W, Section 3, MDB & M. Access to the site is provided by a paved county road which crosses the axis. The USGS Paskenta quadrangle with a scale of 1:62,500 and a contour interval of 50 feet, and a Department of Water Resources map with a scale of 1:4800 and contour interval of 20 feet, provide topographic coverage of the site.

A dam would be required at the site for the development of Newville Reservoir, a part of the Glenn Reservoir Complex. If constructed to an elevation of 1,014 feet, the maximum elevation feasible because of topography, the dam would be about 400 feet high and 5,000 feet long at the crest.

Purpose and Scope

The purpose of the investigation was to evaluate, for planning purposes, the geologic conditions in the area as related to their effect on the construction of a dam. The investigation consisted principally of geologic mapping of the foundation. No foundation drilling has been performed at the site.

Previous Investigations

Previous investigations at the site include only geologic reconnaissance examinations. Rocky Ridge, which forms the abutments at the site, was investigated in 1961 to evaluate its stability and leakage potential. The results of that investigation, which included diamond drilling and water testing, are reported on in this chapter.

Geology of the Site

The topography near the damsite consists of relatively flat valleys separated by narrow resistant ridges which extend nearly north-south along the strike of the rock units. The dam would be located in a gap in one of these ridges (Rocky Ridge) where North Fork Stony Creek has eroded through the ridge on its way eastward to its junction with Stony Creek and the Sacramento River. Rocky Ridge is rather low, with

relatively steep sides, and the dam would encompass portions of the ridge which forms the abutments. Plate 11 shows the approximate outline of the fill, geology, and the topography of the site.

The rocks which make the foundation at the site are all sedimentary and belong to two different geologic units, the Knoxville formation and the Paskenta formation, of Jurassic and Cretaceous age. The contact between the two formations is considered to be near the bottom of the ridge on the western side. Similar rock types in the two formations have essentially the same physical properties.

The foundation rock consists of interbedded mudstone, sandstone, and conglomerate. The beds strike nearly north-south, or parallel to the dam axis, and dip about 60° east, or downstream. In general, the central portion of the ridge which forms the abutments consists of resistant beds of sandstone and conglomerate and the flanks consist of softer mudstone.

The bedrock is moderately well exposed at the site. Portions of the foundation are obscured by colluvium, terrace material, and stream channel deposits. The right abutment and part of the left abutment contain a rather thick soil cover, and the upstream portion of the channel contains gravel and terrace deposits which cover the bedrock. However, the rock units are quite consistent in attitude, and a sufficiently accurate geologic map can be prepared by projecting contacts from locations where the bedrock is exposed.

The mudstone is dark gray, moderately soft, and forms good outcrops only in the stream channel, or in the bottom of gullies. The mudstone consists of a mixture of clay, silt, and a small amount of fine sand. Upon exposure to air, the clay in the mudstone dehydrates and shrinks, and the rock slakes to small angular fragments. This slaking extends to a depth of about 1 foot in fresh rock. Where the mudstone contains considerable sand-sized particles, the slaking tendency is greatly reduced.

The mudstone units outlined on Plate 11 contain many thin interbeds of fine-grained sandstone, which probably make up about 10 percent of the total thickness of the units. These sandstone beds, which are usually separated by several feet of mudstone, average about 6 inches in

thickness, but occasionally are over 12 inches thick. The bedding in the mudstone is obscured by the slaked fragments, but the thickness of the individual mudstone beds ranges from several inches to a fraction of an inch.

The sandstone is gray, moderately hard, and usually well cemented. It is commonly fine-grained, but occasional beds are coarse-grained. The sandstone in the central portion of the ridge is usually massively bedded, with occasional beds as thick as 20 feet, but near the flanks of the ridge the beds average less than 1 foot in thickness. Near the center of the ridge, the sandstone often grades into conglomerate both parallel and perpendicular to the strike of the beds.

The conglomerate is predominantly gray with varicolored well rounded chert and metavolcanic pebbles which range in size from a fraction of an inch to over 12 inches. The conglomerate has a matrix of sand and argillaceous material, and is usually well cemented, but occasional beds are poorly cemented and easily eroded. The conglomerate occurs in massive beds, many of them well over 20 feet thick, which tend to be rather lenticular. The conglomerate is the most resistant rock type at the site and forms bold massive outcrops in places, but many of the outcrops are subdued and much of the conglomerate is covered with soil and slopewash.

Terrace deposits occur at several places in the foundation area, principally in the upstream portion near the channel. The streams have cut down through the deposits, leaving them exposed in steep banks adjacent to the channel. The deposits consist principally of silt and some silty gravel, and average about 15 feet in thickness.

Thin deposits of sand and gravel occur in portions of the stream channels. In places, the gravels are absent and the stream flows on bed-rock. The average thickness of the stream channel deposits, outlined on Plate 11, is less than 5 feet.

Several faults are present in the foundation area of the site. They all appear to be nearly vertical. The major fault, which trends about N40E, crosses the channel near the axis, and has offset the left abutment about 700 feet to the east in relation to the right abutment. A portion of this fault, or a shear zone related to it, can be observed

in the channel just downstream of the bridge crossing the creek which is adjacent to the upstream portion of the right abutment. The exposed portion of the shear zone is only about 2 feet wide, but part of it is covered by colluvium. The zone contains fractured rock but essentially no gouge. The fault is not visible at any other place in the foundation, as it is covered with colluvium and terrace deposits, but its position can be located by terminated beds.

Another fault, which trends approximately east-west, is present in the channel area. It could not be observed nor exactly located since it is covered with channel and terrace deposits, but offset beds indicate its existence.

A fault with an apparent displacement of about 250 feet occurs in the saddle at elevation 926 feet on the right abutment. The fault zone is obscured by colluvial material and could not be observed. Its presence is indicated by offset beds.

Other smaller faults appear to be present on the left abutment, but the lenticular nature of the conglomerate and sandstone beds, and the lack of good outcrops, make detection and accurate location difficult. However, it appears there is at least one minor fault on the left abutment, and there may be more.

In addition to the above faults, there are many small, very narrow faults with displacements of 2 to 3 feet visible in the channel a short distance downstream from the site. Essentially all of them show rehealing with calcite and appear to be tight and impervious. This indicates that the larger faults are probably also rehealed to some extent.

Foundation Conditions

The mudstone is the weakest of the three rock types at the site. Various handbooks and building codes give an allowable bearing capacity of 10 to 15 tons per square foot for this type of rock, but this does not take into account such factors as the size and shape of the structure, and the maximum allowable settlement. The value is intended to be an estimate only, and not a sound basis for design. Based on tests of similar type rocks, the average unconfined compressive strength of the

mudstone is estimated to be as much as 2,000 psi, or 144 tsf. It is believed the mudstone has sufficient strength to provide an adequate foundation for a dam of the desired height, if stripped to fresh, unslaked rock.

The sandstone and conglomerate are much stronger than the mudstone. Thirty-one tests to determine the unconfined compressive strength of fresh sandstone and conglomerate core obtained by diamond drilling along Rocky Ridge, showed an average unconfined compressive strength of 8,700 psi for the conglomerate, and 11,800 psi for the sandstone. Some poorly cemented beds with strengths much lower than this occur in the foundation, but they make up a small part of it. The sandstone and conglomerate have sufficient strength to provide an adequate foundation for the dam if they are stripped to fresh or slightly weathered rock.

The faults which have offset the beds in the foundation will require some special treatment during construction, but they are not expected to present a great deal of difficulty. None of the faults are active and they are all believed to be narrow and relatively impervious. The faults will require some dental work to remove highly fractured, weak foundation rock, but they are not expected to require any special measures beyond a normal grout curtain to reduce their permeability.

Clearing will consist of removing a light covering of oak trees on the left abutment, and a moderate covering on the right abutment. The upstream portion of the channel is nearly clear.

Stripping of the foundation will consist of the removal of terrace and channel deposits, soil, weathered rock, and slaked mudstone in the impervious zone. The following table summarizes the stripping estimates.

Stripping Estimates

Channel

15 feet of terrace deposits

5 feet of stream channel deposits

3 feet of slaked and weathered bedrock

Left Abutment

5 feet of soil and colluvium

10 feet of slaked and weathered bedrock

Right Abutment

8 feet of soil and colluvium

10 feet of slaked and weathered bedrock

An estimated 75 percent of the terrace deposits could be salvaged for use as semi-pervious material. The material is mostly silt with some silty gravels. About 75 percent of the stream channel deposits -- sand and gravel -- could be salvaged for use as pervious, but the amount available is very small. Approximately 75 percent of the soil and colluvium could be salvaged for use as impervious. About 50 percent of the weathered bedrock could be salvaged for use as impervious. The slaked fresh mudstone is probably not suitable for use in the fill, since it would be highly pervious when placed, but after a period of time it would probably break down, consolidate, and become impervious. Also, since the mudstone slakes quite rapidly after exposure to the atmosphere, it may be necessary to protect the mudstone beneath the impervious zone during the period between stripping and placing of the fill, or progressively strip the foundation as the fill is placed. Gunite would probably be the best method of protection.

The rocks which make up the foundation are essentially impervious, and leakage is not expected to be a problem. The faulting which occurs in the channel has undoubtedly produced many fractures which could contribute to leakage, and a grout curtain should be constructed to intercept possible leakage. The grout take is expected to be low.

Spillway

Several saddles in Rocky Ridge are well suited topographically for use as a spillway. The elevation of the reservoir surface would affect the selection of the most desirable one. During the investigation of Rocky Ridge, hole RR-8 was drilled to determine the suitability of that saddle for a spillway site. The mudstone and the weathered sandstone and

conglomerate would erode quite rapidly in a spillway channel where the velocity of the water would exceed 10 feet per second. Lining would be required in at least part of the spillway channel.

Diversion Tunnel

Tunneling conditions should not differ appreciably between abutments, therefore the diversion tunnel can be located where most convenient. However, the tunnel could be slightly shorter with the same elevation of cofferdams if it were located through the left abutment. A recommended alignment is shown on Plate 11. Its location is chosen to avoid any faults which cross the ridge.

Tunneling conditions are expected to be good in fresh rock. The rock load is expected to be about $0.5 B + H$ in the mudstone, and about $0.35 B + H$ in the sandstone and conglomerate. The mudstone would slake continuously if exposed to the atmosphere. The tunnel should be fully lined to prevent slaking and erosion.

Construction Materials

An investigation for construction materials for all the dams connected with the Glenn Reservoir Complex is reported on in this chapter. Plate 15 shows the location of the various construction materials in the vicinity of Newville damsite.

Conclusions

1. The foundation is suitable for an earthfill dam 400 feet in height.
2. The rocks in the foundation are essentially impervious, but a grout curtain should be constructed to intercept seepage through fractures. The grout take is expected to be low.
3. There are no active faults at the site. The inactive faults in the foundation will require some dental work, but no unusual construction difficulties are anticipated.
4. The diversion tunnel should be fully lined and supported. Tunneling conditions are expected to be good.

Recommendations

1. No foundation exploration has been performed at the site. The abutments and channel section should be investigated with drill holes to determine depth of overburden, relative permeability of the rocks, and the condition of the fault zones in the foundation.

2. The strength and bearing capacity of the mudstone should be determined by laboratory and field tests.

Rancheria Damsite

Rancheria damsite is located on Stony Creek, 20 air miles west of Willows, in T21N, R6W, Sections 14 and 23, MDB & M. Access to the site is provided by a paved road from Willows to within about 5 miles of the site, and by a private graveled road which crosses the axis. The USGS Elk Creek quadrangle, with a scale of 1:62,500 and contour interval of 50 feet, and a Department of Water Resources map with a scale of 1:4,800 and contour interval of 20 feet, provide topographic coverage of the site.

For the complete development of the Glenn Reservoir Complex, a dam would be required at Rancheria damsite, or at Millsite (Julian Rocks) damsite, which is 2.3 miles downstream. At Rancheria damsite, a dam with a crest elevation of 1,000 feet would be about 400 feet high and 5,000 feet long.

Purpose and Scope

The purpose of this examination was to evaluate the geologic conditions in the area in relation to their effect on the construction of a dam at the site. The investigation was directed toward the preparation of a geologic map. A study of construction materials for all the dams connected with the Glenn Reservoir Complex was completed prior to this study. The damsite has not been drilled.

Previous Investigations

Previous geologic investigations at the site consisted of a brief examination and reconnaissance outline report. Also, during an investigation for construction materials for the dam, the stream channel was drilled with an auger up- and downstream from the axis to determine the thickness of the stream channel deposits, and several auger holes were drilled to determine the thickness of the terrace deposits at and near the site. Logs of the holes are available in the Northern Branch Geology files.

Geology of the Site

Outcrops of bedrock are very scarce at the site. The upper parts of the abutments are covered with soil, the lower parts are covered with terrace deposits, and a wide deposit of sand and gravel blankets the channel. However, the bedrock is well exposed in steep banks adjacent to the channel. Since the rock units at the site have a very consistent attitude, a geologic map of the foundation was prepared primarily by projecting the geologic contacts from the outcrops near the channel to the abutments.

The foundation rock at the site is all sedimentary and belongs to the Shasta series, of Lower Cretaceous age. It consists of mudstone with interbedded sandstone, and a small amount of siltstone. Mudstone comprises about 75 percent of the dam foundation. The beds strike nearly north-south, parallel to the dam axis, and dip about 65° east, or downstream.

Three types of geologic units were mapped in the bedrock portion of the foundation area: (1) mudstone, with interbedded sandstone comprising less than 10 percent of the unit, (2) mudstone, with interbedded sandstone comprising about 30 percent of the unit, and (3) sandstone, with minor interbedded mudstone. Unit (1) underlies the major portion of the foundation. The contacts between the above three units are usually gradational and based on interpretation. Overlying the bedrock are terrace deposits at two elevations, and gravels in the stream channel. Plate 12 shows the relationship of all these units.

The sandstone is gray, moderately hard, mostly fine-grained, and usually thin-bedded. The individual beds average about 3 inches in thickness, but the thickness varies from a fraction of an inch up to 24 inches. The sandstone beds are usually separated by several feet of mudstone, but in places the sandstone beds are sandwiched together and form units up to 100 feet thick. The sandstone is more resistant than the mudstone, and occasionally siltstone forms resistant beds. This greater resistance of the sandstone to erosion is the reason for the existence of the ridges which form the abutments at the site. The valleys extending perpendicular to the stream channel upstream and downstream from

the axis have been eroded in the softer mudstone. The sandstone is lightly jointed at right angles to the bedding. On the abutments, the sandstone occasionally outcrops but it is usually covered with soil. Good outcrops occur only near the channel.

The mudstone is dark gray, soft to moderately hard, and usually very thinly bedded, although the bedding is difficult to see. It is composed of a mixture of clay, silt, and fine sand. Upon exposure to air, the clay within the mudstone dehydrates and shrinks, cracks develop, and the mudstone slakes to small angular fragments. This slaking usually extends to a depth of about 1 foot in fresh rock.

Terrace deposits overlie portions of the bedrock near the channel. The right abutment has terraces at elevations 630 and 690, and the left abutment has a narrow terrace at elevation 630. The terrace deposits consist mostly of clayey gravels and average about 7 feet in thickness, based on the results of the auger drilling. They are not well consolidated and should be stripped beneath all portions of the dam.

The stream channel is underlain by a wide deposit of sands and gravels. Auger holes indicate they average about 12 feet in thickness at the site. The deposits consist of moderately clean sands and well rounded gravels up to several inches in diameter. They should be stripped beneath all portions of the dam.

Several small faults with displacements of up to about 3 feet were observed at the site, but they are all very narrow, and appear to be impervious. Many have been rehealed by the deposition of calcite in the fault zone. There is no fault with significant displacement in the channel, since similar rock units on each side of the channel line up along the strike. It is believed that any faults which occur in the foundation are minor and will require very little remedial work.

Foundation Conditions

The mudstone is the weakest of the rock types which make up the foundation. Various handbooks and building codes give an allowable bearing capacity of 10 to 15 tsf for rock of this type but this does not take into account such factors as the size and shape of the structure,

or its ability to withstand settlement. Based on rock tests of similar type rock, the average unconfined compressive strength of the mudstone is estimated to be between 1,500 and 2,000 psi. The central portion of the foundation area contains about 30 to 40 percent sandstone, which is estimated to have an unconfined compressive strength of 6,000 to 8,000 psi. The sandstone is thus desirably located, since it occurs in the area where the maximum load would be imposed on the foundation. The critical portions of the foundation, if they are critical, appear to be upstream and downstream of the sandstone section, where the weight of the overlying material would have to be supported almost entirely by the weaker mudstone. It is believed that the mudstone, if stripped to fresh, unslaked rock, has adequate strength to support a dam of the desired height without requiring unusual measures to maintain stability of the foundation. The bearing capacity of the mudstone should be determined by testing, however.

All the faults which were observed at the site were very narrow, had very little displacement, and appeared to be impervious. Some faults may be uncovered during stripping which may require dental work, but the amount is expected to be very minor.

Clearing will consist of removing a moderate growth of oak trees on the right abutment and a light growth on the left abutment and in the channel. Much of the foundation area is clear of brush or trees.

Stripping will consist of removing the terrace and stream channel deposits, soil, weathered rock, and slaked mudstone under portions of the dam. Stripping requirements will be relatively light, and they should be essentially the same under all sections of the dam.

In the channel, the sand and gravel averages about 12 feet in thickness at the axis. It should be removed under all sections of the dam. Essentially all of it could be used for pervious fill, or processed and used in filters or drains. In addition, an estimated 3 feet of slaked and weathered bedrock beneath the gravels should be removed.

On the right abutment, the lower terrace averages 8 feet in thickness, and the upper terrace 7 feet. One hole penetrated 15 feet of terrace material in the lower terrace. All of this material should

be stripped. In addition, an estimated 5 feet of slaked and weathered bedrock beneath the terraces should be stripped. Elsewhere on the abutment, an estimated 5 feet of soil and an average of 10 feet of weathered rock should be removed. The terrace deposits consist of clayey gravel, suitable for use as impervious fill, and an estimated 85 percent of the stripped terrace deposits could be salvaged. The soil to be stripped is a clayey silt, and should be suitable for use as low-strength impervious material. The soil is noticeably thicker on the right abutment than on the left. An estimated 75 percent of the stripped soil could be salvaged. Probably no more than 50 percent of the underlying slaked and weathered bedrock could be salvaged.

Auger hole No. 1 on the right abutment reportedly penetrated 18 feet of decomposed mudstone before contacting fresh mudstone. Usually the mudstone in the auger holes was found to be fresh within 5 feet of the bedrock surface, and often within 2 to 3 feet. No faulting could be observed at the hole, although faulting would be difficult to detect. The deep weathering may be due to erosion or leaching beneath the old stream channel, or it could be that a softer bed was encountered. This limited exploration indicates that there are areas in the foundation where deeper stripping or dental work may be required.

On the left abutment, the terrace averages about 5 feet in thickness. It should be removed, plus an estimated 5 feet of weathered bedrock beneath it. It is estimated that 80 percent of the terrace deposit could be salvaged for use as impervious fill. On the rest of the abutment, about 3 feet of soil and 10 feet of slaked and weathered bedrock beneath it should be stripped. Approximately 50 percent of the soil and 50 percent of the weathered bedrock could be salvaged.

The slaked fresh mudstone consists of small angular fragments which are very pervious, and should be stripped beneath the impervious section of the dam. Since the mudstone slakes rapidly after exposure, it is desirable to progressively trim the foundation as the embankment is placed or protect the foundation underlying the impervious section from exposure during the period between stripping and placing of the fill. Protection could probably best be accomplished by guniting.

The slaked mudstone appears to be unsuitable for use in the fill. A sample taken about 1 mile west of the site and tested in the laboratory consisted of sharp angular fragments, 97 percent of which were between No. 16 and minus 3/4 inch. After 40 cycles of wetting and drying, the material broke down to where 60 percent of it was minus 200. It is believed that compaction equipment would not break the fragments down to an impervious material if it were used in the fill. The material when placed would be highly pervious, but after a period of time it would break down, consolidate considerably, and become relatively impervious.

The following table summarizes the stripping estimates.

Stripping Estimates

Channel

12 feet of sand and gravel

3 feet of slaked and weathered bedrock

Left Abutment

Beneath terrace

5 feet of terrace deposits

5 feet of slaked and weathered bedrock

Remainder of Abutment

3 feet of soil

10 feet of slaked and weathered bedrock

Right Abutment

Beneath lower terrace

8 feet of terrace deposits

5 feet of slaked and weathered bedrock

Beneath upper terrace

7 feet of terrace deposits

5 feet of slaked and weathered bedrock

Remainder of Abutment

5 feet of soil

10 feet of slaked and weathered bedrock

The bedrock in the foundation is essentially impervious and leakage through the fractures or abutments could occur only along fractures. Leakage at the site is not expected to be a problem since the rock is lightly jointed, faulting is minor and has not caused extensive fracturing, and the fault zones observed are not extensive nor are they permeable. A grout curtain should be constructed however, to intercept any possible leakage through fractures. It is believed the grout take will be low. Incidentally, portions of the rim of the reservoir would be formed by thin, narrow ridges, and all narrow portions should be evaluated in relation to their leakage potential.

Spillway

There are several saddles in the narrow ridge along the reservoir rim which are well suited topographically for a spillway. Two of them are near the site, to the north and south. In these saddles, the ridge consists of the same material that underlies the dam foundation, mudstone and sandstone. The rocks are relatively soft and would erode rapidly in spillway channels where the velocity of the water exceeds about 10 feet per second. Also, the slaking of the mudstone would increase the rate of erosion. Lining will be needed in portions of the spillway channel to prevent excessive erosion. On the crest of the ridge, the depth to rock suitable for foundation for a spillway is estimated to be about 20 feet. Cut slopes should be about 1-1/2:1.

Diversion Tunnel

The rock conditions are essentially the same on both abutments, and the diversion tunnel can be located where most convenient. The rock load is estimated to be about 0.5 B + H. The mudstone in the tunnel would slake continuously if left exposed to the atmosphere. The tunnel should be fully lined to prevent slaking and erosion.

Construction Materials

An investigation of construction materials for all the dams connected with the Glenn Reservoir Complex is reported upon in this chapter. No further work was accomplished during this investigation.

Conclusions

1. The foundation is suitable for a properly designed fill-type dam 400 feet in height.
2. There are no active faults at the site, and only insignificant, inactive faults were observed.
3. The rocks in the foundation are essentially impervious, but a grout curtain should be constructed to intercept seepage through fractures. The grout take is expected to be low.
4. A diversion tunnel can be located where most convenient. It should be fully lined and supported.

Recommendations

1. No foundation exploration has been performed at the site. The foundation should be drilled to determine the depth of overburden, the depth of weathering of the rock, and the relative permeability of the rocks.
2. The strength and bearing capacity of the fresh unslaked mudstone in the foundation should be determined by testing.

Millsite Damsite

Millsite (Julian Rocks) damsite is located on Stony Creek, about 20 miles west of Willows, in T21N, R6W, Sections 1 and 12, MDB & M. Access is provided by a paved road from Willows to within 4 miles of the site, then by graveled road and unimproved dirt road to within about one-quarter mile upstream of the axis. The USGS Fruto quadrangle, with a scale of 1:62,500 and contour interval of 50 feet, and a Department of Water Resources map with a scale of 1:4,800 and contour interval of 20 feet, provide topographic coverage of the site.

The site is an alternative to Rancheria damsite, which is 2.3 air miles upstream. At one of the sites, a dam would be required for the complete development of Glenn Reservoir Complex. If Millsite Dam were constructed to an elevation of 974 feet, the highest elevation considered, the dam would be 425 feet high and about 7,200 feet long.

Purpose and Scope

The purpose of this investigation was to evaluate geologic conditions in the area as related to construction of a dam at the site. The investigation consisted of geologic mapping of the foundation and the preparation of this report.

Previous Investigations

Previous investigations at the site include a brief reconnaissance investigation and outline report by the Department in 1960. A search for construction materials, including auger drilling, was performed at about the same time. The U. S. Bureau of Reclamation explored the site in about 1923 for a 135-foot slab-and-buttress type dam. Their investigation included geologic mapping, three test pits, and 19 diamond drill holes. The results are published in Division of Water Resources Bulletin 26, "Sacramento River Basin", published in 1931.

Geology of the Site

Three rock types underlie the foundation: mudstone, sandstone, and conglomerate, listed in order of abundance (see Plate 13). The rocks occur in beds striking nearly north-south, or parallel to the dam axis,

and dipping about 50° to the east, or downstream. The rock belongs to two different geologic units: the Shasta series of Lower Cretaceous age, and the Chico group of Upper Cretaceous age. The contact between the two has been mapped at the base of the conglomerate.

Outcrops of the bedrock are scarce at the site. The abutments are covered with soil, the lower portion of the left abutment is covered with terrace deposits, and the channel is covered with sand and gravel. The bedrock is exposed in steep banks adjacent to the channel, and in gullies. Outcrops on the abutments are essentially limited to conglomerate and some sandstone.

The conglomerate is the strongest and most resistant rock type at the site. On the left abutment it occurs in two massively bedded units, each about 50 to 75 feet thick, separated by interbedded sandstone and mudstone. The two units join and form one thick unit on the right abutment. Discontinuous, lenticular sandstone beds occur within the conglomerate units. The conglomerate consists of well-rounded pebbles and cobbles up to 12 inches in diameter, in a matrix of fine-grained material. The rock is cemented with argillaceous material and iron oxide, and is tight and impervious. The Bureau of Reclamation planned to place the slab-and-buttress dam on the conglomerate and, after their investigation, concluded it was satisfactory for this purpose.

The sandstone is fine-grained, moderately hard, and less resistant to erosion than the conglomerate. In the Chico group some of the sandstone beds contain a large amount of angular mudstone fragments. The sandstone occurs in beds which average less than 6 inches in thickness, but occasionally are up to 2 feet thick. They are usually separated by several feet of mudstone. In places, however, the sandstone beds occur together and form thick units. These were mapped where they are exposed near the channel and projected to the abutments. Outcrops are so scarce on the abutments that contacts between units cannot be observed there.

The mudstone is gray, consists of a mixture of clay, silt, and sand, and is soft to moderately hard. It is thinly bedded to laminated

but the bedding is obscured by the slaking tendency. Upon exposure to air, the clay within the mudstone dehydrates and shrinks, the rock develops cracks, and it disintegrates into small angular fragments. This slaking extends to a depth of about 1 foot in fresh rock. The mudstone units, as shown on Plate 13, contain many thin interbeds of sandstone.

A broad terrace overlies the bedrock on a large portion of the left abutment and a small portion of the right abutment. The terrace deposits are well exposed in steep banks adjacent to the channel, and appear to be about 5 feet thick. The deposits consist of clayey gravels. Upstream of the axis, the lower terrace is considerably thicker, and consists of silts, fine sands, and gravels. It underlies only a small portion of the foundation.

The stream channel contains a wide deposit of sand and gravel which averages about 18 feet in thickness, based on auger drilling. The sand and gravel is quite clean, and is well suited for use as pervious fill.

There are no active faults at the site, nor are there any large inactive faults. Only very small, narrow faults were observed, and they are of no consequence. It is believed that any faults which exist in the foundation are minor and will require very little remedial work.

Foundation Conditions

The mudstone is the weakest of the three rock types which comprise the foundation. Various handbooks and building codes give an allowable bearing capacity of 10 to 15 tons per square foot for rock of this type. This does not take into account such factors as the size and shape of the structure, nor its ability to withstand settlement. Based on tests of similar rock, the unconfined compressive strength of the mudstone is estimated to be about 1,500 psi. The strengths of the sandstone and conglomerate are considerably higher than this, probably three to four times, but they make up only about 25 percent of the foundation. Also, they are mostly upstream of the area where the maximum load would be exerted by the fill on the foundation. The mudstone is believed to

have sufficient strength to provide an adequate foundation for a fill-type dam 425 feet high without requiring special design or provisions to maintain the stability. However, the bearing capacity of the mudstone should be determined by testing.

Clearing will consist of removing a light growth of oak trees from the foundation area. Much of the area is free from any brush or trees.

Stripping will consist of removing stream channel deposits, terrace deposits, and weathered rock. Total stripping requirements should be relatively light, and about the same under all sections of the dam. It should be noted these estimates of stripping are made without benefit of drilling, except auger drilling in the terrace and channel deposits.

Two auger holes in the channel downstream of the dam indicate that the average thickness of the channel deposits is about 18 feet. However, two U. S. Bureau of Reclamation diamond drill holes penetrated gravels to depths of 28 and 58 feet. The holes apparently encountered a pothole eroded in the mudstone and sandstone. The location of the holes is shown on Plate 13. The channel deposits (sandy gravels) should be stripped under all sections of the dam, and in addition an estimated 3 feet of underlying slaked and weathered bedrock should be removed. Over 90 percent of the gravels could be salvaged for use in the pervious section of the dam, or processed and used in filters or drains. The slaked fresh mudstone probably could not be used in the fill since it would be highly pervious when placed, but it would eventually break down, consolidate considerably, and become impervious.

On the right abutment it is estimated that an average of 8 feet of soil and 10 feet of slaked and weathered bedrock should be removed under the entire embankment. An estimated 60 percent of the stripped material could be salvaged for use as moderately low-strength impervious fill.

The left abutment contains a terrace, downstream from the conglomerate, at elevation 580 feet. One auger hole, and exposures in the

steep bank on the south edge of the terrace, indicate that the terrace material averages about 5 feet in thickness. It should be stripped beneath the dam. The material consists of clayey gravel suitable for use as impervious fill, and an estimated 75 percent could be salvaged for this purpose. Upstream from the conglomerate, two terraces occur on the left abutment, one at elevation 565 and the other at elevation 600. The lower terrace averages about 10 feet in thickness in the area it occupies in the foundation. Upstream it is considerably thicker, up to at least 20 feet. It consists of layers of fine sand, silty sand, silt, and some gravels. About 75 percent of it could be salvaged for use as semi-pervious. In addition to the stripping of the terrace deposits, an estimated 5 feet of underlying slaked and weathered bedrock should be removed, 50 percent of which could be salvaged for use as impervious fill. Elsewhere on the abutment, an estimated 5 feet of soil and 10 feet of slaked and weathered bedrock should be removed. About 50 percent could be salvaged for use as impervious.

Since the mudstone slakes rapidly after exposure to the atmosphere, protection of the mudstone beneath the impervious section from exposure during the period between stripping and placing of the fill, or progressive trimming of the foundation, would be desirable. Protection could probably best be accomplished by gunite.

The following table summarizes the estimates of stripping requirements.

Stripping Estimates

Channel

18 feet of sand and gravel

3 feet of slaked and weathered bedrock

Left Abutment

Beneath Terrace

5 feet of terrace material

5 feet of slaked and weathered bedrock

Remainder of Abutment

5 feet of soil

10 feet of slaked and weathered bedrock

Right Abutment

8 feet of soil

10 feet of slaked and weathered bedrock

All rock types in the foundation are essentially impervious, and leakage could occur only through fractures. The U. S. Bureau of Reclamation reported water loss in fractures as deep as 56 and 65 feet in the diamond drill holes in the conglomerate. However, the rocks are lightly jointed, faulting is very minor, and leakage is not expected to be a problem. A grout curtain should be constructed to intercept any leakage through fractures. It is expected that the grout take will be low.

Spillway

A spillway located on the left abutment around the end of the dam would require a cut about 40 feet deep. The water would be discharged into a gully which would convey it well downstream of the dam.

Bedrock at this location is mostly mudstone and sandstone with some conglomerate. Stripping of approximately 20 feet of material would be required to reach sound bedrock on which to found the spillway. Cut slopes should be at about 2 to 1. The mudstone and some of the sandstone would erode quite rapidly when water velocities exceeded about 10 feet per second. Also slaking of the mudstone would hasten erosion. Thus, at least a portion of the spillway would require lining.

Diversion Tunnel

Tunneling conditions will be essentially the same on each abutment; therefore, the diversion tunnel can be placed where most convenient. The rock load is estimated to be about $0.5 B + H$. Lining will be required to prevent slaking and erosion of the mudstone and the softer sandstone.

Construction Materials

An investigation of construction materials for all the dams associated with the Glenn Reservoir Complex was completed earlier and

the results are contained in a later section of this chapter. Nothing in addition was accomplished during this investigation.

Conclusions

1. The foundation is suitable for a properly designed earth-fill dam 425 feet high.
2. The rocks in the foundation are essentially impervious and leakage through the foundation is not expected to be a problem providing a grout curtain is constructed to intercept seepage through fractures. The grout take is expected to be low.
3. There are no active faults at the site. The observed faults are very minor, and any faults found in the foundation will require very little remedial work.
4. The diversion tunnel should be fully lined and supported. It can be located where most convenient.

Recommendations

1. No foundation drilling has been performed by the Department at the site. The foundation should be drilled to determine depth of overburden, depth of weathering, and relative permeability of the rocks in the foundation.
2. The strength of the mudstone should be determined by testing.

Chrome Dike

The proposed Chrome Dike is in the N $\frac{1}{2}$ of Sections 32 and 33, T22N, R6W, MDB & M, and is designed to divide the Rancheria and Newville portions of the Glenn Reservoir to facilitate integrated project staging.

A paved county road passes through the channel section of the site. The proposed dike would have a crest length of about 4,000 feet with the crest elevation at 1,000 feet above sea level. The maximum height of the structure would be 100 feet. A 65-foot high saddle dike will have to be constructed in a narrow saddle east of the left abutment.

Foundation exploration was accomplished by drilling 21 auger holes with a Department of Water Resources truck-mounted Williams auger. Some of the holes were 18 inches in diameter, some were 10 inches in diameter. All holes were drilled to refusal or to a depth of 25 feet, the maximum obtainable with the auger rig.

Geology of the Site

Chrome Dike is underlain by flat-lying recent terrace deposits and east-dipping Cretaceous shales and sandstones. Recent terrace deposits cap the right abutment and also cover the entire channel section. The main objective of foundation drilling was to determine the depth of both terraces and their suitability as foundation material. The depth of the alluvial terraces averages about 25 feet and is at least 40 feet thick near the center of the valley. These features are shown on a reconnaissance geologic map on Plate 14.

Terrace alluvium consists mainly of clayey to silty gravels, with lenses or interbeds of semiplastic silty clay. Shelby tube samples were taken in the clayey members to determine the shear strength and consolidation characteristics of the material.

The clayey terrace gravels are believed to be relatively impervious, and appear to have adequate shear strength. Pebble size material is predominantly composed of rounded to angular fragments of schist and serpentine, indicating a westward source. Well-rounded pebbles derived from the conglomerate of Rocky Ridge were found only in the slopewash and soil immediately adjacent to the left abutment of the dike, and were

underlain by material derived from pre-Cretaceous rocks. Water was encountered in five drill holes at a depth from 17 to 23 feet.

Bedrock is represented by shales with occasional thin sandstone interbeds belonging to the Knoxville formation of Jura-Cretaceous age. The approximate shale-sandstone ratio is 75/25. Bedrock series at the site have a north-south strike and a homoclinal eastward dip from 40° to 80°. Numerous small cross faults and joints cut the rock nearly normal to the strike. Some minor seepage along bedding planes and cross-fractures may be anticipated. The bedrock should accept only a minimum of grout. No major faults were mapped in the vicinity of the site.

Stripping Estimates

Stripping of alluvium in the channel and bedrock on the abutments should be accomplished by common excavation. A core trench averaging 25 feet in depth is recommended under the entire channel section to insure cutoff.

CHROME DIKE SITE

Stripping Estimates

Note: All common excavation at Chrome Dike and Saddle Dike.

Zone	Channel	Right Abutment (West)	Left Abutment (East)
Pervious	1 foot (gravelly clay)	1 foot (gravelly clay)	1 foot (gravelly clay)
Impervious	25 feet (average across channel which will remove all channel fill material in- cluding pervious water-bearing gravels.)	5 feet (shales and gravelly)	5 feet (shales)

SADDLE DIKE "A" (Elevation 935)

Stripping Estimates

Zone	Channel	West Abutment	East Abutment
Pervious	8 feet	1 foot	1 foot
Impervious	8 feet	5 feet	5 feet

Construction Materials

Earthfill material suitable for impervious fill appears to be in ample quantities within a 2-mile radius of the site. Impervious fill consists of alluvial terrace deposits -- silty to clayey gravel. The material appears to have excellent embankment characteristics.

A favorable quarry location exists above the left (east) abutment near the top of Rocky Ridge. Pervious and rockfill material would consist of sandstone and conglomerate. A limited quantity of rock suitable for riprap can be obtained from well-cemented sandstone and conglomerate beds.

The nearest source of concrete aggregate appears to be in the stream channel of Stony Creek 3 to 4 miles south of the site.

Plate 15 shows the location of various construction materials in the Glenn Reservoir.

Tentative Conclusions

1. Chrome Dike site appears suitable for the proposed earth-fill structure.

2. Alluvial terrace deposits in the channel section should not present any major problems during construction of the dike.

3. Lenses of clay of relatively low strength have been found at the site. They appear to be discontinuous and should not present any major foundation settlement problems.

Glenn Reservoir Complex Construction Materials

An extensive field sampling program was conducted during 1959 and 1960 to determine the quantity and characteristics of the potential borrow material for the proposed dams and saddle dikes of the Glenn Reservoir Complex. The sampling was accomplished with an auger drill in the unconsolidated material and the potential quarry sites were tested with three diamond drill holes.

The following types of material were investigated: (1) Impervious fill - Tehama formation, terraces and slopewash; (2) Pervious fill - stream channel deposits; (3) Rockfill and riprap - Jurassic and Cretaceous sandstone and conglomerate, Franciscan formation meta-volcanic or basic igneous rock, resistant igneous units in the serpentine belt. Location of the borrow areas and the exploration holes is shown on Plate 15. Table 7 summarizes types of materials and quantities available. Table 8 presents a summary of test data pertaining to Tehama formation materials.

Tehama Formation

The Tehama formation in the Glenn Reservoir area consists of flat lying, weakly consolidated continental sediments. The formation is composed of poorly sorted unconsolidated silts, clayey silts, sands, and clayey gravel predominantly of yellow, buff, and red-brown color.

This unit will provide virtually all the impervious fill for the proposed Newville and Rancheria (or Millsite) dams.

Terraces

Terraces in the reservoir area appear to be reworked Tehama sediments and generally consist of clayey-silty gravel with silt and clay lenses. The terraces are generally shallow and discontinuous with the exception of terraces T-23 and T-13 to T-15 which contain a considerable volume of usable material (see Plate 15).

The terrace materials have not been adequately tested at this time and will require further study. Detailed work was concentrated on terraces in the vicinity of the Chrome dike site and the Rancheria and Millsite damsites for use in the impervious section.

Stream Alluvium

Virtually all usable alluvium is concentrated along the channels of Stony, Grindstone, and Thomes Creeks. A preliminary estimate shows that about 24 million cubic yards of sand and gravel are located within a 5-mile radius from Rancheria and Millsite damsites. The Paskenta Dam will utilize the channel alluvium of Thomes Creek which lies within a short haul distance from the site. No large alluvial deposits are located near Newville damsite and the use of gravel and sand in the dam section will probably be confined to filters and drains only.

Rockfill and Riprap

Two sources of rock to be used primarily as riprap have been outlined on Plate 15. Quarry areas designated as QA-1 to QA-3 and QA-7 and QA-8 consist of Jurassic to Cretaceous conglomerate and sandstone of the Knoxville formation. Potential quarries QA-4, QA-5, and QA-6 contain rock units of the Franciscan formation ranging from basic meta-volcanic rock to ultrabasic intrusives. The location and the estimated volumes of rock available from the proposed quarry areas are shown on Plate 15 and Table 7.

TABLE 7

BORROW AREAS FOR GLENN RESERVOIR -
QUANTITIES OF MATERIALS

Borrow area	Material	Borrow properties	Volume (million yards)
TF-1	Tehama Fm.	Impervious	198
TF-2	Tehama Fm.	Impervious	141
TF-3	Tehama Fm.	Impervious	257
TF-4	Tehama Fm.	Impervious	46
T-1 to 10	Terrace and slope wash	Impervious	6
T-11 to 16	Terrace and slope wash	Impervious	19
T-17 to 19	Terrace and slope wash	Impervious	0.5
T-20 to 23	Terrace and slope wash	Impervious	12
T-24 to 28	Terrace and slope wash	Impervious	11
T-29 to 32	Terrace and slope wash	Impervious	6
T-33 and 34	Terrace and slope wash	Impervious	7
G-1 to 6	Stream gravel	Pervious	17
G-7 and 8	Stream gravel	Pervious	2
G-9 to 12	Stream gravel	Pervious	5
G-13 and 14	Stream gravel	Pervious	1.8
G-15 to 17	Stream gravel	Pervious	0.1

TABLE 7 (Cont.)

Borrow area	Type	Borrow	Volume
	material	properties	(cubic yards)
QA-1 (Williams Butte down to elevation 1,350)	Conglomerate and sandstone	Weath. zone - semipervious Fresh rock - free draining	900,000 3.5×10^6
QA-1 (elevation 1,350 to elevation 1,300)	Conglomerate and sandstone	Fresh rock - free draining	1.8×10^6
QA-2 (quarry vertical depth = 100 ft.)	Conglomerate and sandstone	Fresh rock - free draining	576,000
	Zone "A"		2.88×10^6
	Shale and fines	Fresh rock - not suitable as rock	144,000
	** Zone "B"	Suitable for random fill zone	200,000
* Quarry vertical depth = 100 ft.			
** Zone "B" is overburden - removal required to utilize Zone "A" rock.			
QA-3	Same as QA-2		
QA-4	Meta-volcanic	Not adequately	
QA-5	basic igneous rocks	mapped for proper yardage evaluation	
QA-6			
QA-7	Approximately same situation as QA-2 and 3, but		
QA-8	probably higher percent waste and/or shale to get fresh rock.		

TABLE 8

SUMMARY OF TEST INFORMATION (7) ON TESHAMA FORMATION

Borrow Material	Lab Number	No. of Tests	Max. Size of Sample	Moisture Content % (Optimum)	Dry Density (lbs./cu.ft.)	Shear Strength		Permeability K (ft./day)	Consolidation (%)	% Fines (-200 Mesh)	Lab Number	LL	PI	Remarks
						ϕ Angle	C = tsf							
						Effect.	Total							
Teshama Formation Triaxial (2) Compression CI (1)	1-2467	1	-3/4"	10.9	118.2 (3)	26.4	(11.5)	0.0	(0.4)	27	1-2467	46	29	Teshama Formation representative of various gradations encountered during exploration.
	1-2468	1	-3/4"	9.8	124.7	31.0	(14.2)	0.22	(0.22)	29	1-2468	45	28	
	1-2466	1	-3/4"	8.9	124.6	35.2	(16.2)	0.36	(0.30)	22	1-2466	56	34	
Teshama Formation Compaction	1-2463	1	-3/4"	10.4	126.0					30	1-2463	49	28	Teshama Formation representative of various gradations encountered during exploration.
	1-2464	1	-1 1/4"	8.3	128.5					22	1-2464	47	27	
	1-2465	1	-1 1/4"	8.6	126.5					30	1-2465	48	30	
Teshama Formation Permeability	1-2470	1						(5)		20	1-2470	49	28	Teshama Formation - Samples tested represent high and low -200 mesh for range of values.
	1-2469	1						0.003 @ 129 per 0.00008 @ 124 per		34	1-2469	44	28	
Teshama Formation Consolidation (Maximum load applied = 40 tsf)	1-2469								(6) 10.3% @ 40 tsf	34	1-2469	44	28	Teshama Formation - Samples tested represent high and low -200 mesh for range of values.
	1-2470								@ 40 tsf	20	1-2470	49	28	

- (1) Consolidated undrained, pore pressures measured.
- (2) Triaxial compression samples chosen as representative as to grading of the various borrow areas except that maximum size would be closer to 2 inches than 3/4 inch. Not enough +3/4-inch material was contained in the samples to warrant testing them with maximum size greater than 3/4 inch. The three samples tested had an average of 10 percent gravel of size 3/4 to 3 inches. This material was scalped prior to sample triaxial testing.
- (3) This sample indicates lower value expected from any of the finer grained Teshama formation. Selective borrowing and field mixing should enable keeping this type of material to a minimum in any proposed dam.
- (4) All density values listed here will be affected slightly (increased) by the increase in gravel content in the field samples. The maximum field size observed (see WA diagrams) was 2 to 3 inches. Specific gravity of the #No. 4 material = 2.73 - 2.83; of #No. 10 material = 2.73 - 2.76.
- (5) Permeability tests run concurrent with consolidation tests. Permeability above is at estimated maximum dry density. Permeability range vs Density Range - Lab. No. 1-2469; 0.006 - 0.0005 ft./day vs 120.2 - 126.2 per (perm. testing discontinued at 126.2 per or load of 10 tsf).
- (6) Restraining load of 1.25 tsf needed to prevent swelling of this sample prior to beginning consolidation testing. Auger log indicates this sample may contain tuffaceous material. No problems in using this material in the fill are anticipated; however, care should be taken to minimize use of tuffaceous zones as compacted fill beneath concrete structures.
- (7) Secondary testing on terrace and gravel deposits was halted in 1961 when funds were depleted. Additional funds were requested to complete the Teshama formation testing only. The properties of these materials were thought to be the most important due to the homogeneous character of the proposed Glenn Reservoir dams.

Rocky Ridge

Rocky Ridge is the narrow ridge which would form a portion of the east rim of Newville Reservoir, a unit of the Glenn Reservoir Complex. Rocky Ridge extends approximately 8 miles in a north-south direction between Section 22, T23N, R6W, and Section 28, T22N, R6W.

Topographic mapping of the area is shown on the USGS Newville and Paskenta quadrangles, both of which have a scale of 1:62,500 and a contour interval of 50 feet. Also, a Department of Water Resources map with a scale of 1:4,800 and contour interval of 20 feet is available for the ridge and the reservoir.

Background and Purpose

Part of the east rim of Newville Reservoir, or that part called Rocky Ridge, is a narrow hogback ridge formed by differential erosion of steeply dipping layers of sedimentary rocks. The ridge has several saddles with elevations lower than the maximum water surface of the reservoir, and contains other saddles with elevations only slightly higher than the maximum water surface. All of these saddles are on or between faults trending transverse to the ridge. Also, the ridge is relatively thin at the crest of these saddles. These features, along with geologic mapping and cross sections are presented on Plates 16 and 17.

Concern has been expressed about the stability of the ridge due to its narrowness, the possibility of overlooking significant factors, and the great potential hazard created by such a large body of water supported for such a long distance by what is in effect a natural dam of unexplored characteristics. Also in question was the practicability of increasing the stability and decreasing leakage, in case such measures were necessary.

In order to proceed with plans for Glenn Reservoir, it was desirable to have expert opinions on the feasibility of the project and especially on the features of the east rim. On May 23, 1960, a consulting board, composed of Roger Rhoades, Consulting Geologist, and John S. Cotton, Consulting Engineer, was convened to consider the practical feasibility of constructing the proposed Glenn Reservoir. As stated by the board in their report:

"The relevant problems are four in number:

1. Closure of the low saddles;
2. Additions, if required, to maintain the structural stability of low and thin parts of the ridge;
3. Possible leakage; and
4. The effect of wave action on the narrower portions of the ridge and the necessity for protection from wave action."

The consulting board concluded in part that:

"1. The ridge is generally stable, but if weak or doubtful sections are disclosed by future investigations, they can be made stable without recourse to extreme or unusual measures. We doubt the necessity of measures to increase the structural stability of the ridge because even in the lowest and thinnest places the ridge seems to have adequate cross section for stability, particularly in view of the competence of the rocks which make up the ridge.

"2. The reservoir will be generally tight with no leakage occurring except in zones of weathered, sheared, or fractured rock, and leakage will be local and of no significant quantity.

"3. The measures required to close the low gaps in the ridge will not be extraordinary in kind or difficulty.

"4. The magnitude and effect of wave action is a matter for further study, but it seems probable that future studies will indicate the necessity for protection, probably by rip-rap, in some places.

"5. It is entirely feasible from the standpoint of stability and leakage to construct the Glenn Reservoir to an elevation not to exceed 1,000 feet, and that this can be done by construction measures of a standard and precedented kind."

The consulting board pointed out that their conclusions were based on a very brief visit to the area, and a study of an uncompleted geologic map of the ridge, without benefit of any subsurface information. In order to obtain more information about the ridge, a diamond drilling program was accomplished in 1960.

The investigation of Rocky Ridge was performed to gain information on the distribution and relationship of the various rock units forming the ridge, the faults which occur in many of the saddles, and the competency and homogeneity of the rocks in the ridge. The structural stability and seepage characteristics of the ridge are dependent on the above conditions.

Scope

The investigation consisted of geologic mapping, diamond drilling in conjunction with water pressure tests, and rock testing of the core obtained by diamond drilling. Eight diamond drill holes, with a total footage of 1,089 feet, were drilled along the ridge. Since the lithology varies considerably in short distances, it was decided to investigate as many potential problem areas as possible and the eight holes were drilled in seven different saddles, one of which is a proposed spillway site. Two holes were located so they would intersect faults at depth. Water pressure tests were conducted where feasible in all the drill holes.

Rock tests, performed in the field, consisted of 31 unconfined compression tests and 14 tensile splitting tests on the core obtained by diamond drilling. The tensile splitting tests were conducted by laying a piece of rock core on its side in an unconfined compression testing machine, and loading it to failure in the direction of its diameter. The tensile splitting strength, assumed to be the true tensile strength, was computed as follows:

$$\text{Tensile strength} = \frac{2}{3.14 \times d \times l} \times P \quad \text{where}$$

P is the load at rupture and d and l the diameter and length of the cylinder, respectively. The shear strength was determined by using the tensile strength and unconfined compressive strength as diameters of Mohr's circles, and drawing a straight line tangent to both circles. The shear strength was assumed to be the intercept of the straight line with the "Y" axis (see Figure 1). Shear strengths determined by this method are only approximate, but tests indicate that the values found by this method are usually conservative, and are reasonably close to the values found by triaxial testing. Average shear strength of seven sandstones tested was 1,540 psi and the average of six conglomerates was 1,450 psi.

A base map with a scale of 1 inch to 400 feet was used in the geologic mapping of the ridge (see Plate 16). Detailed geologic mapping was not considered necessary at this stage of the investigation, and the individual beds in the ridge were not mapped. Instead, the rocks were

broken down into units, based on the predominant rock type in each unit, and the contacts between these units were mapped. Most of the contacts are only approximately located as there was not enough time to walk out each contact, and the contacts are often covered by colluvium. Due to the lenticular nature of the beds, and the many thin beds, detailed geologic mapping of the ridge would be a very time-consuming task. (See the geologic crosssections through the drill holes, Plate 17.)

Regional Geology

The proposed Glenn Reservoir Complex lies in the foothills of the Coast Ranges geomorphic province, very near to its border with the Great Valley of California. The eastern border of the Coast Ranges is characterized by strike-ridges and valleys in sedimentary rock of Upper Mesozoic age. The western border of the Great Valley is underlain by east dipping Cretaceous and Cenozoic sedimentary rocks which form a deeply buried synclinal trough lying beneath the Great Valley along its western side.

Relief in the reservoir is low, with broad valleys between strike-ridges composed of steeply dipping resistant rocks. To the west of the reservoir, the Coast Ranges rise steeply to over 7,000 feet on the drainage divide between the Sacramento River and the Eel River.

Geologic formations in the area include, from west to east, the Franciscan formation of Jurassic age, the Knoxville formation of Upper Jurassic and possibly Lower Cretaceous age, and the Paskenta and Horsetown formations and the Chico group, all of Cretaceous age. To the east of the reservoir, unconformably overlying some of these formations, is the Tehama formation of Pliocene to Pleistocene age.

The Franciscan formation lies to the west of the reservoir. Rocky Ridge is probably in the Knoxville formation, near its contact with the Paskenta formation. Rock types in the reservoir are all sedimentary and include mudstone, sandstone, and conglomerate, dipping steeply to the east. In places, the bedrock is overlain by flat-lying terraces of clayey gravels. To the east of the reservoir, the rock types and structure are essentially the same, but the beds are unconformably overlain by the

Tehama formation which dips to the east at about 3 degrees. The Tehama formation is an alluvial deposit and consists of sandy, clayey gravels of varying gradation, uncemented but well consolidated. It is the prime source of construction materials for the dams associated with the project.

A major fault, now inactive, occurs a short distance to the west of the reservoir. It trends nearly north-south and roughly follows the contact between the Franciscan and Knoxville formations. Another large inactive fault occurs about 2 miles north of Rocky Ridge. It trends northwest-southeast and passes close to the small town of Paskenta. There are many other faults in the reservoir area and across Rocky Ridge, but they are all relatively minor and none are active.

Geology of the Ridge

Structure. Rocky Ridge is a narrow hogback ridge composed of steeply dipping resistant beds of conglomerate and sandstone interbedded with less resistant beds of mudstone (see Plate 16). (The term "mudstone" is used here to include all those rocks which are finer grained than sandstone. In places this "mudstone" is actually a siltstone, a shale, or a claystone.) The ridge is part of an eastward dipping homocline in which the beds dip rather uniformly at about 60° to 80° . The ridge trends nearly north-south, but faults have offset portions of the ridge and the beds usually strike about $N10^{\circ}$ to $20^{\circ}W$. (See Plate 16.) The variation in the attitude of the beds is due to both the faults and the lenticular nature of many of the beds.

The highest elevation on the ridge is 1,320 feet, and the lowest is 600 feet in the stream channel at Newville. A profile along the crest of the ridge is uneven and shows high points separated by saddles. Some of the saddles are below, and some only slightly above, the originally planned maximum water surface elevation of 960 feet. The crest of the ridge is rather sharp, and the ridge is thin in the low saddles at an elevation of 960 feet.

The sides of the ridge have approximately the same slopes. On the upper part of the ridge, the maximum slope is about $1\frac{1}{2}:1$, with an average close of $2\frac{1}{2}:1$. Partway down the ridge this slope gradually

flattens to about 4:1, then farther down, near the base of the ridge, the slope becomes considerably flatter. This lower break in slope is at different elevations on different parts of the ridge. Near Newville, the break is at about 700 feet elevation, but it is at higher elevations to the north and south of Newville. In the Newville area, the ridge is thinner to a lower elevation, and therefore less stable, than any other portion of the ridge.

Rock Units. Five different rock units were mapped across the ridge. They are: (1) mudstone, (2) sandstone with conglomerate, (3) conglomerate with sandstone, (4) sandstone with conglomerate, and (5) mudstone (see Plate 16). Units 2, 3, and 4 make up the central portion of the ridge and the mudstone, units 1 and 5 occur on each side.

Conglomerate. The central portion of the ridge is composed predominantly of conglomerate beds and sandstone beds sandwiched together into one thick section. The individual conglomerate beds, many of which are lenticular in shape, differ considerably in their physical characteristics. Some are very coarse-grained with cobbles up to 12 inches in diameter, while others are finer-grained with pebbles no larger than 3 or 4 millimeters. Most beds are well cemented and hard and fresh a short distance below the ground surface, but a few others are poorly cemented, have low strength, and are deeply weathered. Although the individual beds in the center of the ridge differ considerably in their physical properties, when considered together as a thick section they make a strong, competent rock unit.

The conglomerate weathers to a brown color, but when fresh it is predominantly gray with vari-colored, usually well-rounded pebbles of chert, volcanics, greenstone, and other minor rock types. The conglomerate contains considerable sand and silt-sized particles, and is cemented with argillaceous material and, in places, some calcium carbonate.

Based on the results of water pressure tests and the appearance of the core, it is believed that the conglomerate is usually only slightly fractured beneath the weathered zone. The core shows many old fractures which have been tightly healed with calcite. There are a few open

fractures in the fresh rock, as shown by staining on the fractures and high water loss during water pressure tests.

The conglomerate is the most resistant rock type in the ridge, but it is usually not as strong as the sandstone. Seventeen unconfined compression tests on unweathered conglomerate core showed an average strength of 8,750 psi. The lowest strength of the samples tested was 4,500 psi. Six tensile splitting tests were performed on the conglomerate core. These were plotted against the corresponding unconfined compressive strength, and the average shear strength of the six samples was found to be 1,450 psi. The lowest shear strength found was 1,100 psi.

Sandstone. Sandstone occurs throughout the ridge, but it is much more prevalent in the central portion, or that portion composed of rock units 2, 3, and 4. It occurs in beds which are often 20 to 30 feet thick but the thickness of the individual beds varies in short distances, and they tend to wedge out along the strike. Within the thick sections, bedding is usually very faint or not visible at all. Bedding planes between the sandstone and other rock types, as observed in the core, are commonly tight and impervious. The contacts are usually gradational and not well-defined bedding planes.

The sandstone is generally lightly fractured below the weathered zone. The core shows many old fractures that have been cemented with calcite. Some open, strained fractures were observed in the core, but they are few in number.

The sandstone varies in grain sizes from very fine-grained up to coarse-grained, with the fine-grained type predominating. The coarse-grained sandstone is usually the stronger of the two types, but essentially all sandstone samples tested had moderate to high strength.

Fourteen unconfined compression tests on unweathered sandstone core indicated an average strength of 11,850 psi. The lowest strength of those samples tested was 5,700 psi. The results of seven tensile splitting tests were plotted against the corresponding unconfined compressive strength, and the average shear strength was found to be 1,540 psi. The lowest shear strength found was 850 psi.

Mudstone. The mudstone usually occurs on the flanks of the ridge on each side of the sandstone and conglomerate units but it is occasionally interbedded with the sandstone and conglomerate. In some places faults have displaced the beds so that the mudstone occurs near the crest of the ridge.

The mudstone is gray, soft, and usually shows bedding. It contains small amounts of sand (about 15 percent or less), and often alternates with thin beds of very fine-grained sandstone. As the amount of sand in the mudstone increases, the strength of the mudstone also increases. The mudstone core commonly slakes to small angular fragments upon drying, but this tendency to slake is reduced as the amount of sand in the mudstone increases. Outcrops of mudstone show slaking to a depth of about 1 foot or less.

The strength of the mudstone was not determined by testing because of its slaking tendency. In order to perform rock tests on the mudstone core, extra care and preparation of the core is necessary.

Faults. Numerous faults with strikes varying between N50°E and S60°E cut Rocky Ridge. The dips of the faults are difficult to determine, but they are probably all steep as the fault traces tend to follow nearly straight lines. The apparent displacement along the faults varies from about 800 feet to less than a few feet.

The fault zones which were observed are narrow, and it is believed that all fault zones in the ridge are narrow, probably less than 10 feet wide. A hole drilled through a fault with an apparent displacement of about 800 feet showed a fault zone only 3 to 4 feet wide at that point. The point of intersection of the drill hole with the fault zone was in conglomerate, and the zone may be wider in less competent rock. Fault zones can be observed in the channel at Newville, and the gouge in these zones is less than 10 feet in width.

The faults are believed to be quite tight, and are not expected to be a cause of any significant leakage through the ridge. However, only a few of the many faults in the ridge were investigated by drill holes, and the core recovery was poor in some on the zones. It is possible that some of the faults may permit leakage from the reservoir.

More exploration by adits, drilling, water testing, and trenching is needed before a positive conclusion can be made. If some of the faults should leak after filling the reservoir, the stability of the ridge would not be impaired, and remedial measures could be accomplished with water in the reservoir.

Stability of Rocky Ridge

Since the ridge is relatively thin, and concern has been expressed about the possibility of its failure, the factors contributing to its stability as well as possible causes of instability should be analyzed.

There are three possibilities to consider in analyzing conditions which could cause failure:

1. Assuming that the entire ridge is impervious, do all portions of it have sufficient stability to resist failure by sliding?
2. If the ridge is not impervious, does a permeable layer or lens occur in the ridge along which hydrostatic pressure could develop and cause a slide or blowout on the downstream side of the ridge?
3. Are fractures present along which hydrostatic pressure could develop and cause failure?

Failure due to piping is not considered to be a possibility since most of the beds which form the ridge are well cemented. The occasional poorly cemented beds which occur in the ridge are sandwiched between well cemented beds.

If it is assumed that there are no pervious beds in the ridge, and that in order for failure to occur a section crossing the entire ridge would have to slide, the ridge is obviously stable. Topographic cross-sections show that even the thinnest saddles in the ridge have sufficient cross section to resist failure by sliding if the entire ridge is impervious.

If the entire ridge is not impervious and hydrostatic pressure could develop in some pervious, confined bedding in the ridge, failure could occur if the rock at that point had insufficient strength and mass

to resist the hydrostatic pressure. The core from the drill holes and the geologic mapping indicate that the bedding planes are tight and impervious, and that there are no pervious beds in the ridge. The three rock types which comprise the ridge are essentially impervious and any permeability will be "fracture permeability". However, only a few holes were drilled in the 8 miles of ridge and it is possible that there may be a pervious lens or bed somewhere in that length. Therefore, an attempt was made to analyze the stability of the ridge assuming a pervious bed exists. A sliding wedge analysis of the shear-friction factor of safety against sliding of the wedge downstream of the assumed pervious bed was made in several of the thinner portions of the ridge (see Figure 2). The following assumptions were used: (1) the pervious bed is completely confined so that the full hydrostatic pressure is tending to slide the wedge, (2) a reservoir elevation of 950 feet, (3) uplift on the wedge is equal to full reservoir head at the heel diminishing in a straight line to zero uplift at the toe, (4) coefficient of friction of 0.7, and (5) shear strength of 200 psi, the estimated strength of the mudstone. The lowest factor of safety found was over 8, with these assumptions.

These values for the factor of safety against sliding are based partially on assumptions, but they are considered to be conservative. The assumed shear strength is obviously conservative. The tested shear strengths of the sandstone and the conglomerate average about 1,500 psi, and only 200 psi was used in the analyses. The assumption for uplift is probably also conservative. The assumed coefficient of friction (0.7) is believed to be close to the actual value, but it may be conservative. In order to make more exact estimates, detailed mapping of thin portions of the ridge will be necessary so that the correct shear strength can be used for each location. It would also be necessary to determine the shear strength of the other rock types, and the coefficient of friction would have to be determined by testing.

In regard to the occurrence of fractures along which unsafe hydrostatic pressure could develop, no factor of safety was computed as the orientation and continuity of fractures cannot be determined with certainty. However, for an unsafe condition to develop, the fractures

would have to: (1) have an attitude such that the strike would nearly parallel the ridge so that the fracture would not daylight and allow the pressure to be relieved; (2) intersect the reservoir near its maximum elevation, and have a dip flatter than 60° , the assumed angle of the pervious bed for which stability computations have been made; and (3) be watertight in order for the maximum hydrostatic head to develop in it. These are essentially the same conditions assumed for the pervious bed.

The same forces which caused faulting in the ridge also undoubtedly caused fracturing, and it therefore is likely that many of the fractures produced by these forces have attitudes similar to the faults. All the faults mapped on the ridge are transverse to it. None were found parallel to the ridge. Also, when stratified rocks are jointed, one joint set is perpendicular or nearly so and the beds are nearly parallel to the ridge. It therefore seems nearly certain that any fractures parallel to the ridge would be intersected by transverse fractures which would drain them and prevent the development of high hydrostatic pressures within the parallel fractures. In view of the requirements for the attitude and structure of fractures so that unsafe pressures could develop in them, the possibility of their existence seems very remote.

It is concluded that all portions of the ridge have adequate stability to withstand the pressure of a reservoir at an elevation of at least 950 feet.

Leakage

Water tests indicate that all three rock types in the ridge are inherently impervious, and for any leakage to occur, water must pass through the fractures in the rock. The core from the drill holes shows many old fractures tightly cemented with calcite, and only occasional open fractures. The open fractures are easily recognized as they are usually stained from the passage of water. Occasionally during drilling all return water was lost and an open stained fracture could be observed in the core from that depth. During water tests, the greater water loss occurred in the top of the holes where weathering had opened fractures. Some of the water losses in the weathered zone were as high as 35 gpm in a 13-foot zone with a pressure of 80 psi.

It was noted that some of the fractures which took considerable water at the start of a test tended to fill up, and the flow diminished steadily during the test. In some holes, an artificial artesian condition was developed by the water test, and most of the water came back from the hole when the packer was released. This indicates that some of the open fractures are not connected and could not contribute to any leakage through the ridge.

In hole RR-8 (see Plate 16), artesian water was encountered at about 65 feet and a small amount (less than 1 gpm) now seeps out of the hole. Minor seeps and springs occur along the ridge, showing that there are fractures which do transmit water. Many of these seeps occur near faults. The water is probably transmitted through fractures which were caused or opened by movement along faults and does not necessarily indicate that the faults are pervious. Although these fractures do exist, it is believed that they will not permit any significant leakage through the ridge. In the event that leakage does occur through these fractures, it is doubtful that this would affect the stability of the ridge, and remedial action could be taken after filling of the reservoir.

The most likely place for leakage to occur is believed to be in low saddles where the water surface closely approaches the crest of the ridge. In these areas the path of percolation is short and may not encounter fresh rock. For example, the saddle in which RR-5 was drilled has a crest elevation of 967 feet (refer to Plates 16 and 17). Assuming a reservoir elevation of 950 feet, the path of percolation through the ridge at this point is only 125 feet long, through soil and weathered rock. At an elevation of 930 feet, the path would be about 200 feet long, and still would not encounter any fresh rock. When the freeboard with the crest of the ridge is less than about 30 feet, the path of percolation through the ridge at this point is only 125 feet long, through soil and weathered rock. At an elevation of 930 feet, the path would be about 200 feet long, and still would not encounter any fresh rock. When the freeboard with the crest of the ridge is less than about 30 feet, the path of percolation often will not intersect fresh rock. Excessive leakage might occur through the ridge where the relatively high permeability

of the weathered rock and the short path of percolation exist. Each low saddle will require detailed investigation, but in general, it is believed that some cutoff may be needed where the freeboard is less than about 30 feet. Cutoff could probably best be provided by a grout curtain.

Roger Rhoades, Consulting Geologist, has stated that relief wells - presumably to localize and enable channeling of any leakage - could take care of any leakage in these areas, should it occur. He suggested this method as he was doubtful that grouting would be effective.

The existing Stony Gorge Dam, located within the Glenn Reservoir area, is built in a gap in a hogback ridge which is similar in lithology to Rocky Ridge. There is a difference in location as related to the dip of the beds however, as the beds dip upstream at Stony Gorge. Also, the Stony Gorge Reservoir does not as closely approach the ridge top as would Glenn Reservoir. However, there is an analogy between the two reservoirs and there has been no problem with leakage through the ridge at Stony Gorge Reservoir. The difference in the dip of the beds in relation to the reservoirs should not affect the leakage, as the bedding planes in the rock at Rocky Ridge are generally tight and will not transmit water.

Grouting

The foundation preparation for Stony Gorge Dam included pressure grouting. This involved the drilling of 160 holes at spacings ranging from 4 to 7 feet in a single line in the bottom of the cutoff trench. The depths of the holes varied from 18 to 40 feet. The holes were grouted at pressures of 90 to 100 psi, and only five holes took more than three sacks of cement each. The other 155 holes averages less than one sack each - little more than enough to fill the hole and grout pipe. Nothing is known about the ratio of water-to-cement used in the grouting program. Grouting was performed only in fresh rock, and the rock was probably conglomerate. It may be that weathered rock, or the mudstone or sandstone will accept more grout.

The consultants stated in their report that:

" . . . excluding the zones of opened joints, shearing, and faulting, we believe that grouting will be unnecessary and, in many cases, ineffective. Some grouting may, in the light of more detailed investigations, prove to be necessary in disturbed or weathered rocks, but if so, it will be sharply localized in small areas, and no large quantity of grout will be required at any one place. It may well be that no grouting whatever will be required even in these locations, but decisions in this regard will have to await drilling and pressure testing."

Water pressure tests and the presence of open fractures in the core indicate that much of the rock can be effectively grouted. Water loss in some zones was as high as 35 gpm at 80 psi over a 13-foot zone. The highest water loss occurred in the weathered zone, and this is the zone that may need grouting in the low saddles. Many of the fractures, especially in the weathered zone, contain clay which will reduce the effectiveness of the grouting. However, if a thin grout is used and the holes are closely spaced (5 feet or less between holes) it is believed that the saddles can be effectively grouted. The grout take is expected to be low.

Most of the faults in the ridge are steep and strike about north-east, and it is assumed that many of the fractures will have about the same attitude. Fractures with attitudes approximately perpendicular to the strike of the ridge could also be a cause of leakage. Therefore, the bearing and inclination of the grout holes should be about parallel to the ridge and 80° or less, respectively. This should ensure that grout holes cross any fractures which could be a source of leakage.

Ridge Protection

Several low saddles, underlain mostly by mudstone, will have freeboards of less than 20 feet. The mudstone slakes in air and will erode quite readily. These low saddles will probably require protection from wave action. Riprap appears to be the best method of protection.

Only the upper part of the ridge would need protection, but the riprap would roll down the steep slopes unless supported from below. It could be supported by placing the riprap from the base of the ridge up to the crest, but this would require a great deal of material. An alternative may be to cut a bench into fresh rock part way down the slope and place the riprap upward from the bench.

Wherever the freeboard is less than about 30 feet, the area should be investigated to determine whether or not riprap is needed. In areas where the waves will impinge upon unweathered conglomerate or sandstone, riprap will not be necessary. Where thin portions of the ridge consist of mudstone it will probably be necessary to protect the ridge from erosion by wave action.

The consultants suggested that the riprap could be installed and maintained most economically by barge as the reservoir filled.

Closure of Saddles in Ridge

At least two saddle dams will be required if the reservoir is filled to 960 feet. The saddle at Burrows Gap, where the Elk Creek-Newville road crosses the ridge, will require a dam about 120 feet high and 800 feet long. The first saddle south of Newville damsite will require a dam at least 45 feet high and 400 feet long.

At Burrows Gap the sides of the ridge slope downward from the crest of the gap at about 15:1 or flatter. The topography appears to be best suited for an earthfill dam. Construction materials, except for riprap, are available within 2 miles. The riprap would have to be hauled about 5 miles.

Stripping depths will probably average about 10 feet under the impervious section. Some minor dental work may be required where an old fault crosses the gap. Grouting will be needed under the impervious section and also the crest of the thin, low ridge extending outward from the ends of the dam.

In the saddle south of Newville, the crest of the ridge is not wide enough for an earthfill dam 35 feet high without part of the dam extending down the side of the ridge. In this saddle, a concrete gravity dam could probably be built more economically than an earthfill dam. A hole was drilled in the crest of the saddle (see Plates 16 and 17), and the foundation appears to be suitable for a concrete gravity dam. The core showed weathering to a depth of 38 feet. Stripping depths are estimated to average about 20 feet, and some dental work will be required. Water loss during pressure tests was high, and grouting beneath the dam and on the crest of the ridge at the ends of the dam would probably be necessary.

There are two other saddles in the ridge with crest elevations at about 950 feet. These would require low dikes to provide some freeboard, but the ridge at these locations is relatively wide. Low earth-fill dikes can be built in these saddles.

Conclusions

Based on limited diamond drilling and geologic mapping, the following conclusions about Rocky Ridge have been made.

1. The ridge has sufficient stability to withstand the force exerted by a reservoir with a maximum water surface at an elevation of at least 950 feet. The reservoir could probably be raised safely to an elevation of 1,000 feet, but the thin portions of the ridge should be reevaluated for stability, and several more saddle dams would be required.

2. No significant leakage from the reservoir will occur if the crests of the low, thin portions of the ridge are grouted. Grouting may be necessary where the freeboard is less than about 30 feet. The numerous faults are not expected to be a cause of significant leakage, but if some of them do leak excessively, it will not affect the stability of the ridge and the leakage can be corrected after the reservoir is filled.

3. Grout take will probably be low and holes will need to be closely spaced to ensure effective cutoff.

4. Where the freeboard with the ridge crest is less than about 30 feet, the upper part of the ridge may need protection from wave action. Riprap appears to be the best method of protection.

5. Where saddle dams must be placed on narrow portions of the ridge, concrete structures may be more economical than fill-type structures. Only one concrete saddle dam would be required if the reservoir elevation does not exceed 960 feet.

6. An earthfill dam will be the most suitable type in the saddle at Burrows Gap. Construction materials, except for riprap, are available within 2 miles of this saddle.

Recommendations

Additional exploration is required prior to construction. The following recommendations are made in regard to the types of exploration needed:

1. Detailed geologic mapping of the ridge, especially the low, narrow portions.

2. Bulldozer or backhoe cuts in the crests of several low saddles. Some of the cuts should intersect fault zones.

3. Tests to determine the permeability of the weathered rock in saddles where the path of percolation does not intercept fresh rock. This should show whether or not grouting or relief wells will be necessary in the low, thin saddles.

4. A test grouting program to determine the effectiveness of grouting and the required spacing of grout holes.

5. At least one adit into the ridge near the Newville area. The adit should be located on the reservoir side and directed so it will intersect a fault zone at depth.

6. Rock testing to determine the shear strength of the mudstone.

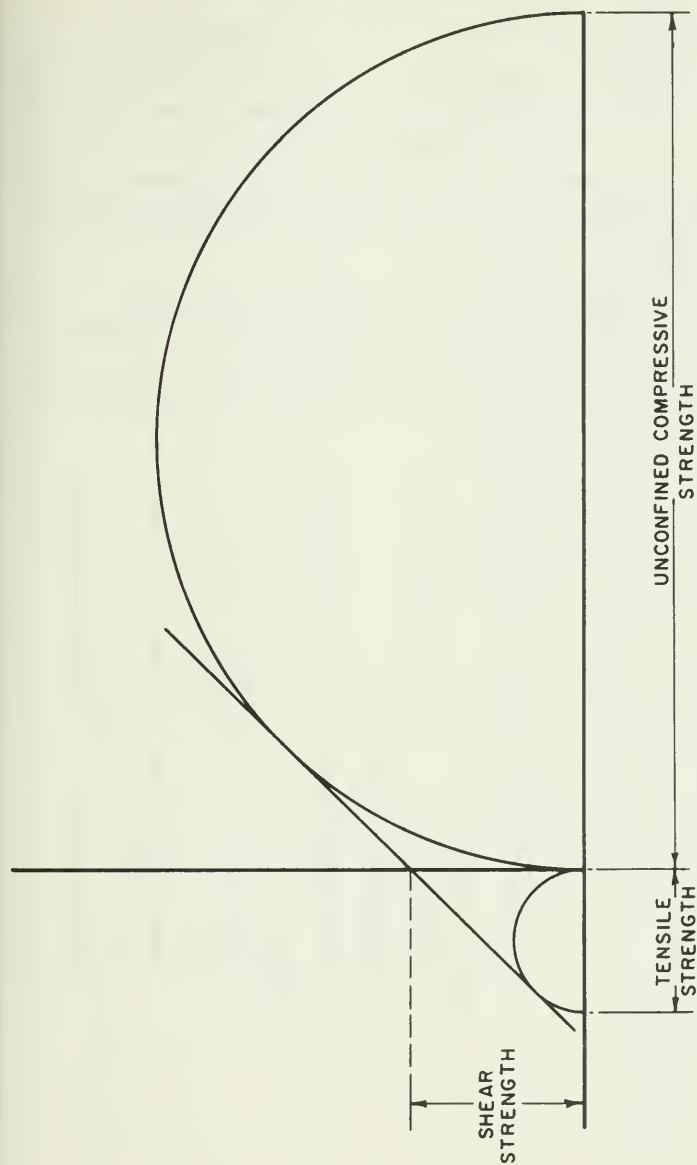
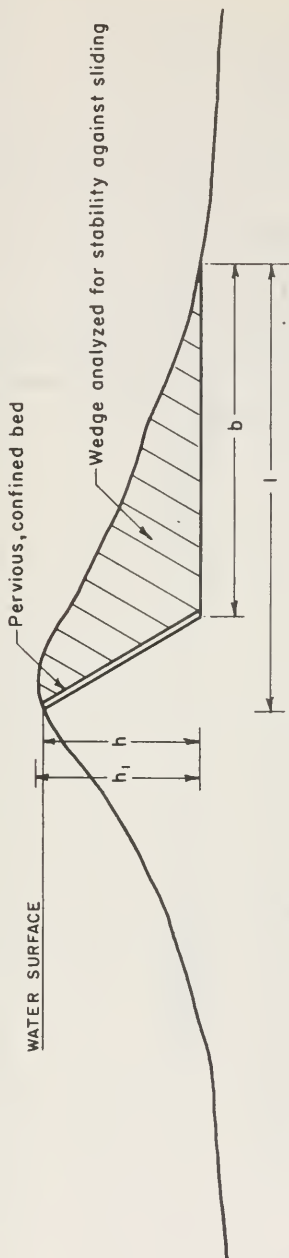


Figure 1. METHOD USED TO DETERMINE SHEAR STRENGTH OF ROCK CORE



$$\text{Factor of safety} = \frac{[(\text{wt. rock} - \text{uplift}) \times (\text{coeff. friction})] + (\text{shear strength} \times \text{area})}{\text{reservoir pressure}}$$

Assumed values :

density of rock = 150 lbs. per cubic foot
 coefficient of friction = 0.7
 shear strength of rock = 200 psi or 28,000 psf

Method :

weight of rock = $\frac{b \times h_1}{2}$ lbs./linear foot
 uplift = $\frac{h \times 62.5 \times l}{2}$ lbs./linear foot
 shear strength x area = 28,000 x b lbs./linear foot
 area = b
 reservoir pressure = $\frac{h^2 \times 62.5}{2}$ lbs./linear foot

Figure 2. METHOD USED TO COMPUTE SHEAR-FRICTION FACTOR OF SAFETY AGAINST WEDGE SLIDING

CHAPTER IV. UPPER EEL RIVER PROJECTS

The engineering geology of principal project features on the upper Eel River are discussed in this chapter. Featured projects shown on Plate 1 include English Ridge Dam and Reservoir and Garrett Tunnel. The geology of Soda Creek Tunnel which would divert water to Putah Creek is also presented. Geologic maps, cross sections, and location of construction materials for these projects are presented on Plates 18 through 21.

Several other damsites on the upper Eel River were also studied, but generally in less detail than English Ridge damsite. Geologic data on these sites, including Garcey Ranch, Marshall, Willis Ridge, and Presley Ranch appear in Table 9 at the end of this chapter.

English Ridge Damsite

English Ridge damsite on the upper Eel River lies in the SE $\frac{1}{4}$ of Section 6, T19N, R12W, MDB & M. The axis of the proposed dam is located about 1,300 feet downstream from the confluence of the Eel River and Old Woman Canyon.

Access to the site is via Berry Canyon Road to the SE $\frac{1}{4}$ of Section 8, and then via an abandoned logging road to the left abutment of the site.

General topography of the site is shown on the USGS 15-minute Eden Valley quadrangle with a scale of 1:62,500 and a contour interval of 100 feet. Reconnaissance geologic mapping was done on a Department of Water Resources map with a scale of 1 inch = 400 feet and a contour interval of 20 feet.

Description of Project

The English Ridge Dam would be part of the Clear Lake Diversion Project which includes features on the Middle Fork Eel River and Garrett and Soda Creek Tunnels.

The proposed 535-foot high earth- and rockfill dam at the English Ridge site would create a reservoir with an approximate storage capacity of 1,800,000 acre-feet at a normal water surface elevation of 1,695.

An uncontrolled chute spillway will be located across a narrow ridge above the right abutment, terminating in a flip bucket which will discharge into the stream channel about 1,500 feet downstream from the toe of the dam about 750 feet from the outlet tunnel portal.

Three crest elevations were considered -- 1,711, 1,670, and 1,570. Preliminary statistics for the three plans are presented below.

Engineering Statistics
English Ridge Dam and Reservoir

	Crest Elevations		
	1,711	1,670	1,570
Normal water surface elevation	1,695	1,650	1,550
Maximum water surface elevation	1,704	1,664	1,565
Minimum water surface elevation	1,450	1,450	1,450
Height of dam in feet	535	490	390
Total volume of embankment in cubic yards	21,427,000	16,411,000	8,700,000

Geology of the Site

English Ridge damsite lies within a northwest-trending sedimentary belt of the Franciscan group, which is composed predominantly of graywacke sandstone with minor lenses and interbeds of black slaty shale. This 2-mile wide belt of resistant rock is bounded to the east and west by sheared and brecciated material which consists of shale, greenstone, serpentine, and glaucophane schist. These areas of weak rock are covered by slopewash and landslide debris and should provide sufficient volume of impervious construction materials for the proposed structure. Based on examination of visible outcrops in the Eel River channel it was concluded that 80 to 85 percent of the dam foundation consists of sandstone, overlain above the channel by generally shallow slopewash and soil.

The strike of the strata in the damsite area is N20 to 35W with predominantly western dips ranging from 35° to vertical. Local reversals of dip are common and several tight plunging folds were mapped. The larger scale folding could not be determined during the brief reconnaissance owing to similarity of rock types and nearly isoclinal folding. No faults or shear zones which may affect the stability of the dam foundation were mapped in the dam area. Geology of the damsite is shown on Plate 18, "Geologic Map and Section".

The reservoir will be entirely in Franciscan rock types and seepage should be minor. Seepage through the narrow ridges which form the right and left abutments could be considerable, especially so on the left side where the strike of the strata is nearly normal to the ridge.

Both ridges should be investigated by diamond drilling during the feasibility stage of the project.

Landslide areas in the channel of the upper Eel River above the site are present but no large scale mass wasting into the reservoir is anticipated. The closest potential landslide lies about 3 air miles southeast of the site. The channel section contains several entrenched meanders between the unstable slope and the site and no serious tidal wave danger appears to exist from sudden landslide movement into the reservoir.

Foundation Conditions

Right Abutment. The right abutment is formed by a narrow plunging ridge underlain predominantly by sandstone. Outcrops are continuous along the base of the abutment up to about 100 feet above the channel. Above this elevation outcrops become more spotty and are surrounded by shallow soil and colluvium. The depth of the overburden probably averages about 5 feet with a maximum of about 15 feet near the crest of the abutment. The strike of the bedding is parallel to the axis of the proposed dam and the section of the rock exposed in the channel should be representative of the remainder of the abutment ridge.

The rock is a gray to greenish-gray, fine-grained, hard gray-wacke sandstone. The thickness of the individual strata varies from a few inches to about 15 feet. The rock is hard and moderately jointed -- average joint spacing is about 1 foot at the surface. The most pronounced joint system is normal to the strike of the strata or parallel to the channel (N30 to 50E), and generally dipping north at a very steep angle. Another well developed joint set is parallel to the bedding. These fractures developed through differential slipping of sandstone strata during regional deformation and folding. Some slickenside and shearing was observed along these joints especially in thin slaty interbeds.

Most joints appear to be open near the surface and numerous small seeps were observed near the channel elevation. Cutoff grouting in the sandstone would probably be effective because of regularity of joints and lack of clayey material in the fractures.

A 60-foot wide shear zone, trending N35^QW was mapped at the base of the right abutment 800 feet upstream from the dam axis. This shear zone consists of crushed shale and sandstone but apparently contains very little clayey gouge. The brecciated rock is saturated and will require some overexcavation and grouting. Several minor faults were mapped near the mouth of Old Woman Canyon and some minor shears were noted along the channel. These structural features are inconsequential and will not affect the stability of the dam foundation.

Foundation preparation on the right abutment for a 535-foot high rockfill dam will consist of removal of all soil and slopewash under the entire dam section -- an average depth of about 8 feet. Some bedrock shaping will be required near the channel to provide an even surface for placement of fill. Stripping under the impervious section will require removal of 5 feet of overburden in addition to 15 feet of weathered and loose rock as averaged over the entire slope. Some overexcavation and minor dental work will be required in several minor shear zones and in some open joints near the channel.

Channel. The stream channel is about 200 feet wide and has an S-shape in the dam foundation area. The average stream gradient is roughly 15 feet per mile. The channel section has continuous sandstone outcrops at the base of both abutments and is filled with stream alluvium. Although no outcrops were found to be completely continuous across the channel, the conformity of attitude and correlation of strata on both sides of the stream indicate that there is no fault beneath the alluvial cover. The depth of sand and gravel is expected to vary from nearly 0 to 25 feet in scour or pot holes carved by the river along prominent joints and weak zones. Considerable scouring can be expected along a major set of joints parallel to the channel near the axis and along the traces of the bedding in the downstream toe area. Bedrock irregularities will require hardrock shaping and concrete dental work, but should not constitute a major construction problem. Stripping in the channel will consist of removal of the alluvium under the entire dam section to expose any possible foundation irregularities or defects. Loose and weathered rock should be removed from the impervious section in addition to shaping.

Overall foundation preparation in the channel will require removal of 10 feet of alluvium plus 3 feet of shaping and loose rock.

Cutoff grouting should be directed to intercept the joint set parallel to the channel. The rock is fresh and the grout take will probably be low.

Left Abutment. The left abutment is formed by a narrow N60°E trending ridge. The average abutment slope along the dam axis is 37°, becoming somewhat shallower (30° to 25°) in the upstream toe area.

Outcrops on the lower portion of the abutment are nearly continuous up to about 50 feet above the channel. Above this elevation outcrops are scarce and the entire slope is mantled by slopewash and some landslide debris. The overall average depth of colluvium on the left abutment is estimated at 15 feet with a maximum depth of 50 feet in the downstream toe area.

Rock types are identical to the right abutment and the channel area -- about 80 to 85 percent graywacke sandstone and 15 to 20 percent shale. Strikes and dips of the strata, and direction and spacing of joints are the same as on the right side.

The rock below the colluvial cover on the upper abutment slope is expected to be deeply weathered -- probably to a depth of 25 to 30 feet. The entire left abutment is covered by dense trees and brush in contrast to the opposite slope which has only a light cover of trees and brush.

Numerous springs and seeps were observed both in colluvium and bedrock and a small gully 800 feet downstream from the axis will have to be diverted during construction and operation of the project.

Foundation preparation on the left abutment will consist of removal of all colluvium from the dam foundation in addition to stripping of weathered and unstable bedrock under the impervious section. Average stripping depths for a 535-foot dam will be 15 feet under the rockfill section and 25 feet under the impervious. Grouting will be required to reduce seepage through open joints and along bedding planes. Grout takes will be moderate to high.

Spillway

The narrow ridge above the right abutment is the most favorable spillway location. Preliminary design calls for an uncontrolled ogee weir

section 450 feet long with a concrete-lined chute, terminating in a flip bucket. A final volume computation indicates that about 3,400,000 cubic yards of material will be excavated for 1,704 maximum water surface plan. Assuming the continuance of rock units from the channel section into the spillway area, the relative proportion of sandstone to shale should be about 80 percent to 20 percent. The depth of colluvium and decomposed rock should average about 20 feet underlain by 20 more feet of weathered rock. The colluvium and weathered rock will probably be suitable for the transition section. The fresh sandstone would be salvaged for the rock-fill section -- about 50 percent of the total excavated volume.

The strike of the sedimentary strata is nearly normal to the spillway cut so that both sides will be equally stable. The cut slopes should be stable at 1.5:1 in overburden, 1:1 in weathered bedrock, and 0.5:1 in fresh hard rock. The spillway will be excavated almost entirely by drilling and blasting.

Diversion and Outlet Works

The right abutment ridge provides the best location for the proposed 35-foot finished diameter diversion tunnel. The tunnel will cut the rock normal to the stratification and the tunneling condition will be "moderately blocky and seamy" with a load factor of 0.35 (B + Ht). Circular steel ribs will be spaced from 6 to 4 feet and the entire tunnel will be lined with concrete.

Some minor faulting was noted near the inlet portal and stripping of unstable rock and rock bolting will be necessary to provide a stable portal face.

An inlet channel will be excavated around the upstream toe of the dam to provide for unrestricted flow of water into the outlet and diversion tunnel. The total volume of excavated material will be about 375,000 cubic yards and the maximum cut depth will be 160 feet. The inlet channel will be entirely in sandstone and the slopes should be stable at 1/2:1 in fresh rock.

Construction Materials

Impervious. The total estimated volume of impervious embankment for the proposed 535-foot dam is 3,800,000 cubic yards.

Three large areas underlain by deep accumulations of soil, slope-wash and landslide debris derived from Franciscan shale, sandstone, and greenstone are outlined on Plate 19. Based on reconnaissance study there are sufficient impervious materials within a 3-mile radius and probably after a more detailed study an adequate volume of impervious fill can be outlined within a 2-mile radius from the site.

Considerable variation in grain size distribution, plasticity, permeability, and unit weight was observed throughout the potential borrow areas and an intensive sampling and testing program is needed during the feasibility study to determine the most advantageous source of material. The distribution of colluvium on the slopes can be expected to be highly irregular with ribs and residual boulders of rock, requiring some selective excavation.

Rockfill and Riprap. Five potential rockfill quarry areas are shown on Plate 19. The aggregate volume of material available exceeds the required 16 million cubic yards and there appears to be no shortage of rockfill material.

The most extensive and the most favorable quarry area appears to be R-1 (see Plate 19). Bold outcrops of hard, massive, slightly weathered sandstone are visible from the channel of Twin Bridges Canyon nearly to the crest of English Ridge -- some 1,000 feet.

The shale content in all five potential quarries appears to be low -- less than 15 percent. During quarrying operations the sandstone is expected to break up into roughly equidimensional fragments with a relatively high percentage of minus 4-inch material. The shale fragments and the minus 4-inch rock will be used in the transitional (semi-pervious) section. Some selective excavation will probably be required to produce good quality, free-draining (4 to 8-inch) rock without extensive processing at the quarry.

A test quarry operation to determine the breaking characteristics and powder requirements for the sandstone is necessary for a feasibility type investigation.

Concrete Aggregate and Filter Material. No adequate source of pervious sand and gravel suitable for aggregate and filter was located near the site. Gravel bars along the Eel River up- and downstream from

the site are generally shallow and discontinuous. The only known sizable gravel deposit in the region lies near the north end of Lake Pillsbury, nearly 20 air miles southeast from the site.

Conclusions

1. Preliminary investigation indicates the foundation is suitable for the proposed 535-foot rolled rockfill dam.

2. Beneath the impervious section of the rockfill dam, the average stripping requirements are: right abutment - 23 feet; channel section - 13 feet; and left abutment - 25 feet. Stripping under the rockfill section will be: right abutment - 8 feet; channel - 10 feet; and left abutment - 15 feet.

3. An around-the-end spillway can be located on the right abutment. The excavated sandstone material will be salvaged for rockfill and transitional sections.

4. The deep colluvium and landslides on the left abutment average 25 feet in thickness; this material can probably be used in the transitional and impervious core sections of the dam.

5. Rockfill and impervious materials are available within a 3-air-mile radius; concrete aggregate and pervious materials are scarce and need further investigation.

Recommendations

Further study of this site should include the following:

1. Detailed geologic mapping of the damsite.
2. Dozer and/or backhoe trenches on both abutments to determine the depth of colluvium and the condition of weathered rock.
3. Diamond drilling and water pressure testing along the dam axis and spillway centerline, to determine the foundation conditions and possible leakage through the ridge above the right abutment.
4. Sampling and testing of potential impervious materials.
5. Investigation for pervious and aggregate materials.
6. Testing of the suitability of rockfill materials, including diamond drilling and a test quarry.

Garrett Tunnel

The Garrett Tunnel is designed to convey water from the proposed English Ridge Reservoir on the upper Eel River into Middle Creek, a tributary of Clear Lake. Two alternative tunnel alignments with inlet portal elevations of 1,500 and 1,600 were considered in the preliminary analysis, with respective tunnel lengths of 48,200 feet and 64,200 feet.

Purpose and Scope

The geologic investigation of the proposed alignment in the Middle Mountain area was conducted during the summer of 1957 to determine the most favorable alignment for Garrett Tunnel. Detailed geologic mapping was conducted during a 7-week period and, in addition, a brief study of water quality was made. Geologic mapping of the tunnel line was done on USGS maps (scale 1:62,500) and aerial photographs. No subsurface data were available.

General Geology

The overall structure of the Middle Mountain area follows a northwest-southeast trend characteristic of the North Coast Ranges. The most significant geologic feature is a belt of the Shasta formation of Cretaceous age consisting of a complex synclinal structure striking northwest and plunging southwest, and which has been down-faulted into rocks of the Franciscan group. The distribution of these rock units and structural features are shown on Plate 20, "Geologic Map and Sections, Garrett Tunnel".

The Cretaceous age rocks can be easily distinguished from the surrounding Franciscan group, primarily by the orderly appearance of the interbedded sandstone shale strata which bear marked resemblance to the Sacramento Valley Cretaceous rocks found in the Coast Range Foothills. The Cretaceous belt (Shasta series) is composed entirely of shale and sandstone with occasional conglomerate lenses, while the Franciscan group contains a great variety of igneous and metamorphic rocks in addition to the sedimentary units.

The structure within the Franciscan is complex and difficult to interpret, chiefly because of lack of exposures. Topographic expression

of structure is indistinct except for geologically recent faults. By contrast, structure in the Shasta series is expressed rather well in the topography, and exposures are sufficient to make a generalized interpretation of the tunneling conditions.

Attitudes on the eastern side of Middle Mountain indicate a northwest strike and moderate to steep southwest dip, modified by local folding. Toward the west the available attitudes become less frequent and quite variable, which is partly a result of surficial slumping and sliding on a dip slope, and partly due to fracturing and shearing near a major fault along the west side of Middle Mountain.

In general it can be stated that the Middle Mountain Ridge consists of a series of northwest-oriented spurs with intervening saddles and gullies which reflect the underlying geologic conditions. The ridges are underlain predominantly by more resistant sandstone while the saddles are formed by weaker shale or thinly bedded sequence of shale and sandstone. Although the sub-parallel arrangement of the topography is easily discernible, it was not possible during the field mapping program to trace out rock units owing to poor outcrops and lack of time.

The belt of Cretaceous sedimentary rock is bounded to the east and west by two major fault zones (see Plate 20). These zones are characterized by intensely deformed rock and a highly diverse, disoriented assemblage of rock types including sheared serpentinite. The two faults are well expressed in the regional topography and appear to have a maximum width of nearly 1 mile locally. Faulting within the Cretaceous rocks was difficult to map owing to deep weathering, especially in weaker or deformed rock units. Based on reconnaissance mapping along the South Eel River, a shear zone within the Cretaceous rocks was mapped about one-quarter mile from the proposed inlet portal. This shear zone is about 300 to 400 feet wide and consists of intensely sheared, locally gougy rock. The degree of shearing and fracturing is at its maximum near the center of the zone, diminishing in intensity to the east and west. The direction of deformation is nearly north-south or roughly parallel to the tunnel alignment. Based on air-photo analysis this shear zone was traced southward across the proposed tunnel. Several other "zones of weakness" were traced on

aerial photographs based on alignment of topographic lows; however, field check proved to be inconclusive owing to lack of exposures.

The degree of jointing in the tunnel area was difficult to interpret. Only two areas of fair outcrops were located. One is along the south bank of the Eel River where a new logging road has exposed an excellent cross section of the Cretaceous belt; the other area of outcrop is less continuous and consists of road cuts in weathered rock along the western flank of Middle Mountain. Based on limited exposures there appear to be three major joint sets. Two sets of fractures are crossing the bedding striking north-south dipping 80° to 65° south and N70W and dipping 75° to 85° north. There are frequent zones of very close jointing with a fracture spacing of 3 to 4 inches. These jointed zones appear to become shears or minor faults locally. In road cuts along the western flank these zones of fracturing are spaced from 20 to 30 feet apart but may represent only local conditions and may not extend to the tunnel alignment. The third set of prominent fracturing is along the bedding and is well exposed along the Eel River. These fractures consist of slippage planes normally along contacts of shale and sandstone. Numerous minor shear zones were noted usually entirely within thinly bedded black shale. Most of these shears were seeping water at the time of observation (late May) and at least one seemed to be mildly sulphurous. Although these zones are minor zones of weakness their orientation is nearly parallel to the alignment and a tunnel could conceivably follow a shear zone for a considerable distance.

Ground Water

The quantity of ground water inflow into the proposed Garrett Tunnel will generally be quite high. The highest flows will occur in closely jointed zones and also along faults and shears under deep cover. It is believed that by placing the tunnel close to the eastern border of the Cretaceous belt most serious water problems will be avoided. The belt of Cretaceous rock is a complicated synclinal structure, and a concentration of water in the trough of the structure can be anticipated, especially since the rocks in the tunnel area are thinly bedded and extensively jointed.

Ten springs on Middle Mountain were sampled for temperature, chloride content, and conductivity. In addition, local residents were queried concerning unusual ground water occurrences in the area and there were no reports of hot springs or chemical springs. All the tested springs were low in temperature, chloride content, and conductivity. It is thus estimated that water at tunnel depth will generally be of good quality (exceptions will occur in fault zones), and will be fairly cool.

Geology of the Tunnel Line

The first consideration in locating the Garrett Tunnel was to avoid the two major fault zones located to the east and west of Middle Mountain, and the badly sheared and deformed sedimentary rocks of the Franciscan group. For this reason the line is placed entirely under Middle Mountain in sandstone and shale of the Shasta series, which provide the best tunneling conditions in the area. Surface evidence on Middle Mountain further indicated that the western side of the Shasta belt is to be avoided, as the rocks appear to be severely jointed and locally sheared. There also seems to be a greater amount of shales on the western side. The center of the synclinal structure as outlined on Plate 20 should also be avoided because of the possibility of dangerous ground water inflows which would be most pronounced in a synclinal trough.

The eastern side of Middle Mountain provides the best tunneling conditions in the mapped area. The optimum location in this limited zone is, however, not predictable from reconnaissance surface mapping and must be determined from subsurface exploration.

The tunnel as located on Plate 20 will be almost entirely in Shasta series sandstones and shales. The geologic structure along the tunnel line is not the most favorable for tunneling purposes. Throughout most of the length, the bedding will be striking roughly parallel to the line, varying perhaps 30 degrees to either side. Similarly, the bedding will dip moderately steeply to steeply toward the west, generally from 40 to 80 degrees. No positively identified faults cross the tunnel line; however, two cross-faults were inferred based on topographic expression and poor outcrops, and there are probably a number of others that do not have surface expression. It has generally proved out from

constructed tunnels that only a small percentage of minor faults and shear zones can be located by surficial mapping. Furthermore, minor faulting and shears may be discontinuous and confined entirely to lenses of shale or other weaker rock and may not outcrop on the surface.

Properties of Rock Units

Sandstones. Tunneling characteristics of the sandstones will vary depending on whether tunneling is carried on in thick massive beds or in thin beds separated by layers of shale. In all cases, the sandstone will be moderately hard and moderately blocky and seamy except in shear or fault zones. Overbreak will be slight to moderate in massive beds greater than 10 feet thick, moderate to heavy in beds from 1 to 10 feet thick (depending on amount of interbedded shales), and heavy in beds 1 foot or less in thickness. Tunneling conditions will vary with the angle of intersection of the tunnel and the bedding. The best tunneling will be normal to the stratification and less favorable conditions will be encountered when progressing obliquely or parallel to the bedding. In general, the tunnel follows the regional structural grain and the attitude of the strata will often parallel the alignment. This condition is considered to be unfavorable to tunneling because considerable overbreak can be expected along the dip of the strata. As the tunnel line will be located predominantly in westerly dipping strata, most overbreak should occur on the eastern side of the spring line. Reversals in attitude were observed throughout the tunnel area and a considerable portion of the tunnel will be crossing the bedding at nearly right angles.

Shales. Tunneling characteristics of the shales will vary in the same manner as for the sandstones. However, overbreak will be heavier, and, in areas of high cover, sheared shales are liable to produce squeezing ground. The thinly bedded shale will slake when exposed to air. However, this should not constitute a major tunneling difficulty, although some slaking will take place in the period between the excavation and lining. Zones underlain predominantly by shale are normally expressed in the topography as lows such as saddles or gullies. Because of their relative softness and susceptibility to weathering, shales do not outcrop as frequently as the more resistant sandstone and a precise determination of

shale horizons was not possible. Several zones probably underlain predominantly by shale were recognized based primarily on air photo interpretation.

Tunneling Zones

The Garrett Tunnel area was divided into three tunneling conditions zones based on the relative cost of tunneling through zones of rock with different physical properties (see Plate 20). The most favorable conditions would be encountered in Zone I and would become progressively worse in Zones II and III.

Zone I. This tunneling zone is underlain by Shasta series sandstone with subordinate shale interbeds. Zone I also covers the entire Shasta series belt where no differentiation of rock units was possible. It thus represents the average anticipated tunneling conditions of the whole belt. The tunneling conditions will range from hard stratified in massive sandstone to moderately blocky and seamy in thinly bedded sandstone and shale. About 10 percent of Zone I will be in shale and in shear zones. Water inflows into the tunnel are expected to be moderate -- only 5 percent of Zone I is expected to be in "wet heading" tunneling.

Summary of Tunneling - Zone I

Rock Condition	: Rock Load Hp : in feet	: Rock Types	: Percent : of Zone
2. Hard stratified	0.5 B	Sandstone	30
4. Moderately blocky and seamy	0.35 (B+Ht)	Interbedded sand- stone and shale	60
5. Very blocky and seamy to com- pletely crushed.	0.7 (B+Ht)	Sheared shale and minor fault zones	10

Zone II. Zone II includes areas within the Shasta series underlain by shale or inferred fault or shear zones. Tunneling conditions are expected to range from very blocky and seamy to completely crushed. About 10 percent of this zone is expected to be in "wet heading" tunneling -- more than 100 gallons per minute at the heading. Moderate lateral pressures should occur especially under more than 1,000 feet of cover. Invert struts will be required throughout Zone II.

Summary of Tunneling - Zone II

Rock Condition	: Rock Load Hp : in feet	: Rock Types	: Percent : of Zone
Very blocky and seamy to completely crushed	0.7 (B+Ht)	Sheared shale and sandstone	100

Zone III. Zone III includes the two major fault zones which parallel Middle Mountain. Only a minor portion of the tunnel near the outlet portal will be in fault zone material. The rock consists of completely crushed locally and chemically altered sandstone, shale, serpentine, and various minor rock types of the Franciscan group.

The rock is expected to be saturated as the excavation will be near the channel of Middle Creek, and flowing ground may be encountered. The tunneling difficulties will be alleviated somewhat by low depth of cover; however, the tunnel will be almost entirely in the weathered and chemically altered material. Invert support and close blocking and lagging will be required in Zone III.

About 20 percent of Zone III will be excavated under "wet heading" conditions.

Summary of Tunneling - Zone III

Rock Conditions	: Rock Load Hp : in feet	: Rock Types	: Percent : of Zone
Completely crushed, chemically altered rock.	1.10 (B+Ht)	Fault zone	100

Conclusions

Based on a preliminary mapping program:

1. The proposed Garrett Tunnel appears to be geologically feasible and no unusual construction difficulties are anticipated.
2. The tunnel will be located in a belt of Shasta series rock which provides the best tunneling conditions.
3. Based on surficial geologic mapping, the principal problems encountered by the tunnel will be (a) heavy overbreak in thinly bedded, steeply dipping shale and sandstone, (b) high inflow of ground water,

especially in shear or fracture zones, and (c) some lateral pressures in sheared, thinly bedded shale under high depth of cover.

Recommendations

1. Additional detailed geologic mapping is needed for a more precise determination of the tunneling conditions zones. This mapping program should include an evaluation of topographic expression as related to the underlying geologic conditions.

2. Exploratory core drilling and dozer trenching should be conducted after completion of detailed geologic mapping to determine the structural relationships and to explore areas of inferred weak rock. Diamond drill holes should be pressure tested at short intervals to gain at least qualitative knowledge of the fracture permeability.

3. An exploratory adit should be excavated to provide information on the tunneling methods best suited for the material rock loads, support requirements, overbreak, lateral pressures, and water inflow. The most favorable location for this adit would be in the Eel River Canyon in a thinly bedded shale-sandstone sequence which shows some shearing. The adit should be oriented parallel with the stratification in order to determine the maximum overbreak, and to test the tunneling condition as will be encountered by the Garrett Tunnel.

Soda Creek Tunnel

Soda Creek Tunnel is designed to transport surplus waters from the Eel River and Clear Lake into the Putah Creek Basin. The tunnel is located in T12N, R6W, MDB & M. Topography is provided by the USGS 15-minute Lower Lake quadrangle sheet.

The proposed 20-foot diameter tunnel will be about 3 miles long and, based on current geologic knowledge, the entire line will be 100 percent supported and concrete-lined. Areal geology and geologic structural interpretations for this tunnel are presented on Plate 21.

An intensive geologic study of the area was undertaken by the U. S. Bureau of Reclamation as part of the Yolo-Solano development in 1948. The tunnel geology was mapped on a topographic map with a scale of 1 inch = 1,000 feet and a contour interval of 10 feet. The engineering geology was described in a USBR office report titled, "Reconnaissance Geologic Report on Clear Lake-Soda Creek Tunnel Line", published in March 1948. No additional field work has been undertaken since this study.

The geology of the tunnel line is summarized below as described in the USBR report.

"A feature considered in studies for the Yolo-Solano development is a diversion tunnel about 3 miles long from Clear Lake to Putah Creek drainage in the northern Coast Range. The area embracing the tunnel site is underlain by strongly folded, faulted, and altered rocks of Jurassic, Cretaceous, and possibly lower Eocene ages unconformably overlain by upper Eocene sandstones. Any tunnel line chosen will be almost entirely in the pre-Eocene rocks. The rocks are dominantly shale and sandstone; small bodies of serpentine and contact-altered rocks are in the area. Two diamond drill holes have been drilled in the area and one choice of line was abandoned as the result of the drilling and geologic mapping. Further exploration and drilling would be necessary to select a final location if a tunnel diversion is desired. The preliminary line chosen for estimating purposes has its inlet portal at Clear Lake Dam and outlet in Soda Creek, a tributary to Putah Creek. The following estimates on required support refer to this line: 37 percent will require light support, 35 percent will require moderate support, and 28 percent will require heavy support. Suitable concrete aggregates for lining are available within 15 miles by hard-surfaced road."

Tunneling Zones

For purposes of preliminary cost estimates the tunnel was subdivided into three tunneling conditions zones based on the geologic conditions as described in the USBR report. The entire tunnel line will lie in intensely deformed rock and tunneling conditions are expected to range from moderately blocky and seamy to completely crushed, moderately squeezing. Heavy ground is anticipated in sheared hydrothermally altered zones with high inflows of hot, mineralized water. Altered shales and mudstones will have a tendency to slake when exposed to air and will require an immediate gunite coating.

Summary of Tunneling Zones

	: : Rock : Condition	: : Load Factor : Hp in feet	: : Percent : of Zone
Zone I	Moderately blocky and seamy	0.35 (B+Ht)	37
Zone II	Very blocky and seamy	0.725 (B+Ht)	35
Zone III	Completely crushed	1.1 (B+Ht)	28

NOTE: About 10 percent of Zone III is expected to be "wet heading" tunneling.

Any further study of the Soda Creek Tunnel line will require detailed geologic mapping and additional diamond drilling. The complex geologic structure does not permit an evaluation of tunneling conditions based on surficial mapping alone. A ground water and spring sampling investigation is highly recommended to determine the properties of the mineralized water with respect to its reactivity with concrete lining.

TABLE 9
GEOLOGIC CHARACTERISTICS OF DAMSITES
Upper Sal River

Location number	Site name	Stream	Foundation conditions	Striping	Spillway	Dimension tunnel	Construction materials	Seam city	Feasible structures	Special problems
See 37, 212N, 212W, 212W, 212W	Garvey Ranch	Sal River	<p>Right Abutment -- The right abutment is composed of sandstone and shale. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present.</p> <p>Channel section -- A major fault passes beneath the channel section. Shearing is extensive in the sandstone. The channel is 10' wide and 10' deep. The left abutment is underlain by sandstone, siltstone, and shale. The channel section is composed of siltstone and shale. Slides are present near the channel.</p>	<p>Estimated for an earthfill dam 350' high. The right abutment is composed of sandstone and shale. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present.</p> <p>Channel section -- A major fault passes beneath the channel section. Shearing is extensive in the sandstone. The channel is 10' wide and 10' deep. The left abutment is underlain by sandstone, siltstone, and shale. The channel section is composed of siltstone and shale. Slides are present near the channel.</p>	<p>A side channel approximately 100' wide and 10' deep. The right abutment is composed of sandstone and shale. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present.</p> <p>Channel section -- A major fault passes beneath the channel section. Shearing is extensive in the sandstone. The channel is 10' wide and 10' deep. The left abutment is underlain by sandstone, siltstone, and shale. The channel section is composed of siltstone and shale. Slides are present near the channel.</p>	<p>A diversion tunnel 3,000' long is proposed on the left abutment over the right abutment. The right abutment is composed of sandstone and shale. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present.</p> <p>Channel section -- A major fault passes beneath the channel section. Shearing is extensive in the sandstone. The channel is 10' wide and 10' deep. The left abutment is underlain by sandstone, siltstone, and shale. The channel section is composed of siltstone and shale. Slides are present near the channel.</p>	<p>I-Grade debris and large boulders are present in the right bank and north-east of the dam site within 15' ft. I-Grade debris, deposits present in the channel and downstream. The site and downstream are stable. Depth to sound rock is about 20'.</p> <p>I-Grade debris and large boulders are present in the right bank and north-east of the dam site within 15' ft. I-Grade debris, deposits present in the channel and downstream. The site and downstream are stable. Depth to sound rock is about 20'.</p>	<p>Low to moderate</p> <p>Low to moderate</p>	<p>Earthfill dam</p> <p>Earthfill dam</p>	<p>A major fault and extensive shearing in the right bank may be expected in over joints and shear zones.</p>
See 37, 212N, 212W, 212W, 212W	Wills Slides	Sal River	<p>The damsite is underlain by hard, massive sandstone, with interbedded black shale, of the massive Franciscan formation. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present.</p> <p>Channel section -- A major fault passes beneath the channel section. Shearing is extensive in the sandstone. The channel is 10' wide and 10' deep. The left abutment is underlain by sandstone, siltstone, and shale. The channel section is composed of siltstone and shale. Slides are present near the channel.</p>	<p>Estimated for an earthfill dam 350' high. The right abutment is composed of sandstone and shale. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present.</p> <p>Channel section -- A major fault passes beneath the channel section. Shearing is extensive in the sandstone. The channel is 10' wide and 10' deep. The left abutment is underlain by sandstone, siltstone, and shale. The channel section is composed of siltstone and shale. Slides are present near the channel.</p>	<p>A side channel approximately 100' wide and 10' deep. The right abutment is composed of sandstone and shale. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present.</p> <p>Channel section -- A major fault passes beneath the channel section. Shearing is extensive in the sandstone. The channel is 10' wide and 10' deep. The left abutment is underlain by sandstone, siltstone, and shale. The channel section is composed of siltstone and shale. Slides are present near the channel.</p>	<p>A diversion tunnel 3,000' long is proposed on the left abutment over the right abutment. The right abutment is composed of sandstone and shale. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present. The sandstone is jointing is well developed and open at the surface. A terrace lies just above the abutment. A slide composed of siltstone and shale is present.</p> <p>Channel section -- A major fault passes beneath the channel section. Shearing is extensive in the sandstone. The channel is 10' wide and 10' deep. The left abutment is underlain by sandstone, siltstone, and shale. The channel section is composed of siltstone and shale. Slides are present near the channel.</p>	<p>I-Grade debris and large boulders are present in the right bank and north-east of the dam site within 15' ft. I-Grade debris, deposits present in the channel and downstream. The site and downstream are stable. Depth to sound rock is about 20'.</p> <p>I-Grade debris and large boulders are present in the right bank and north-east of the dam site within 15' ft. I-Grade debris, deposits present in the channel and downstream. The site and downstream are stable. Depth to sound rock is about 20'.</p>	<p>Low to moderate</p> <p>Low to moderate</p>	<p>Earthfill dam</p> <p>Earthfill dam</p>	<p>A major fault and extensive shearing in the right bank may be expected in over joints and shear zones.</p>

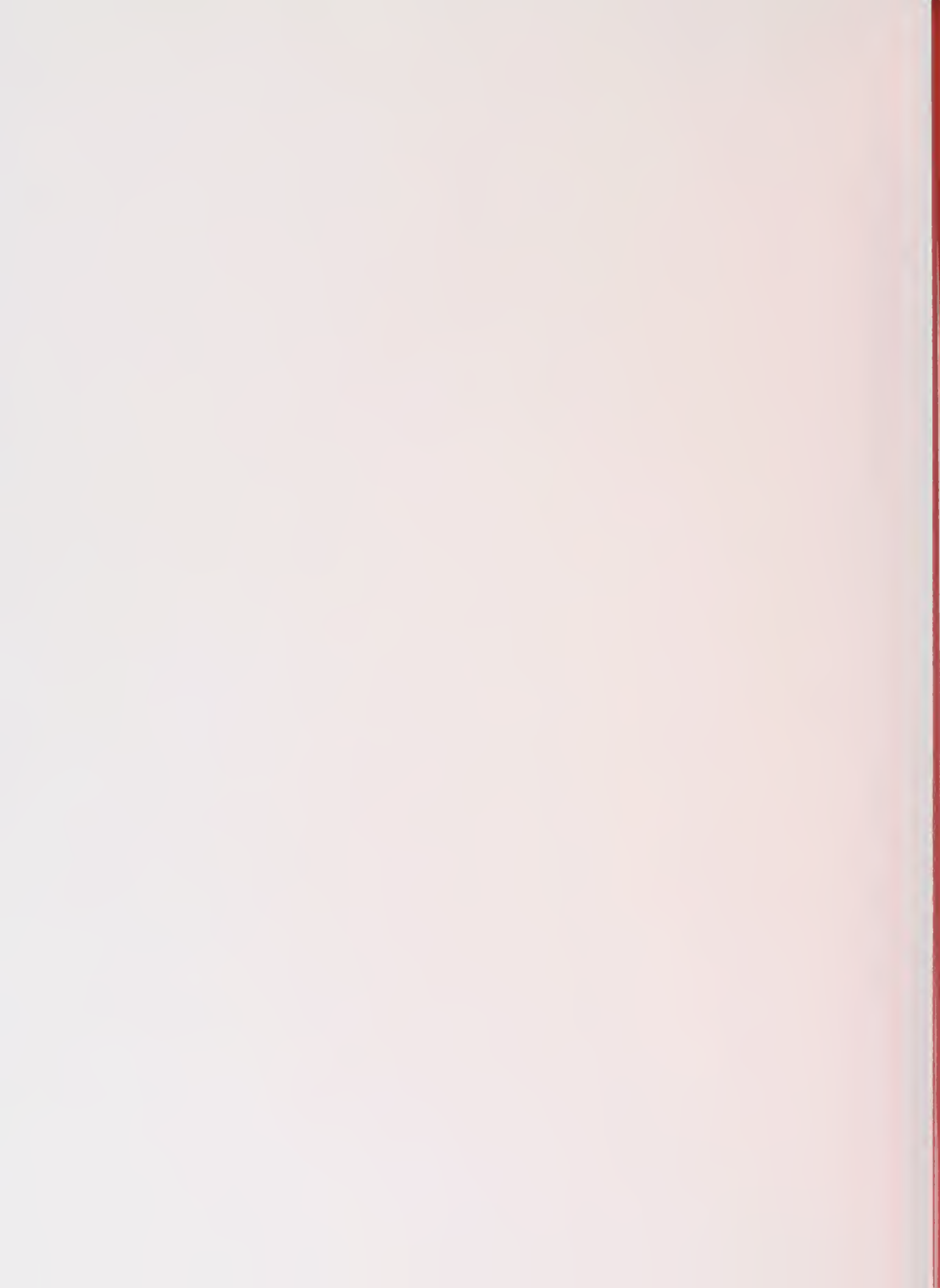
TABLE 2 (continued)

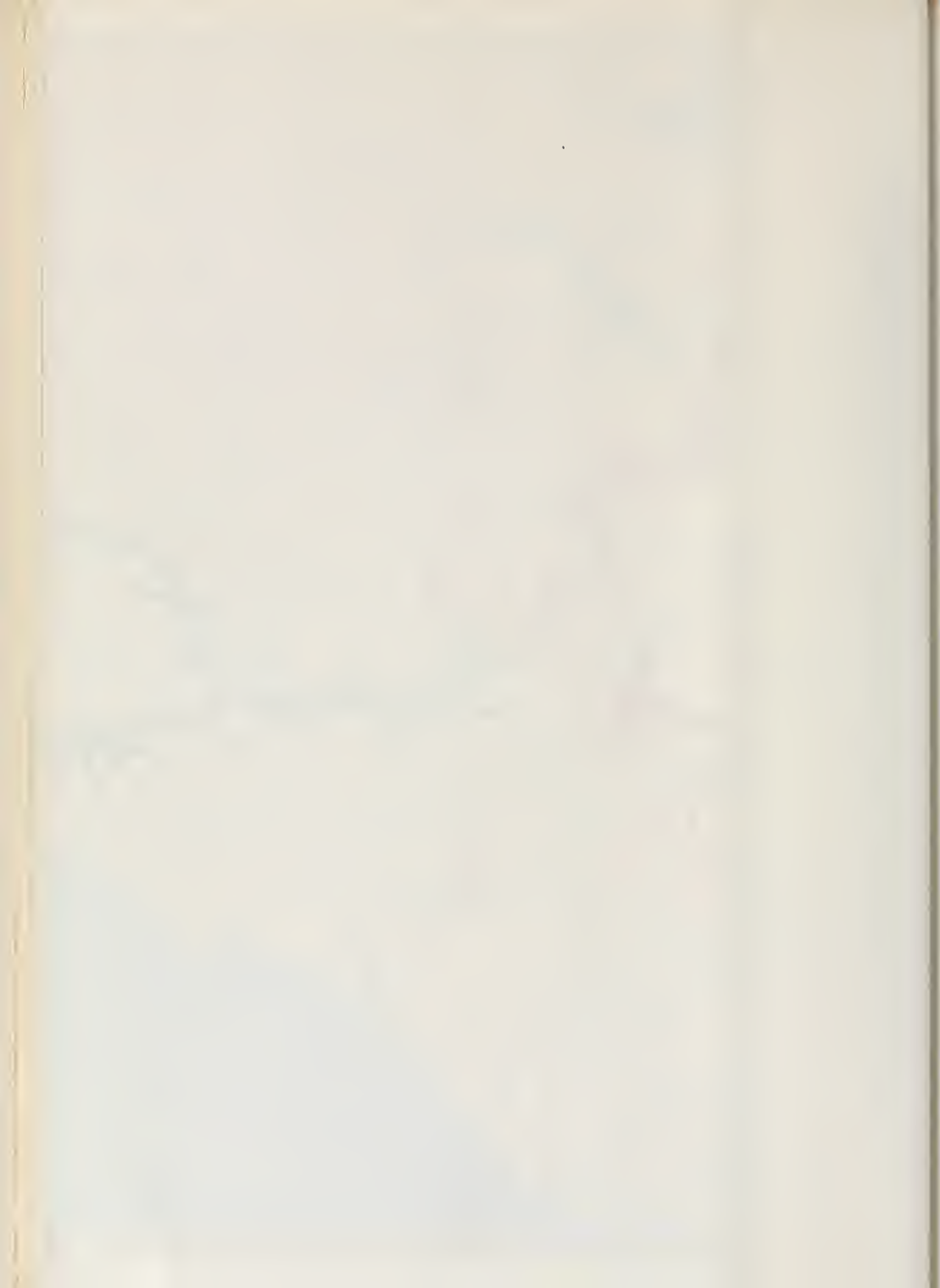
Location number	Site name	Watershed	Foundation conditions	Drilling	Driveway tunnel	Construction materials	Existing structures	Special problems
See 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000	Right Abutment -- Bedrock is exposed in the lower portion. Overburden varies in thickness to a maximum depth of 10'. Two holes were drilled in the left abutment. Core recovery varied from 82% to 91%. After tests in the shale were inconclusive. In sandstone tests were poor because of weathering. Channel section -- Bedrock is well exposed in the channel. A thin veneer of fill, up to 3' thick, occurs in places. Black shale is present in the channel. Two holes were drilled in the channel. Core recovery varied from 77% to 84%. In hole LC-1, between 110 and 150 feet, a thin veneer of fill was observed with a water loss of 7-1/2 gpm. Left Abutment -- Bedrock is exposed on the lower portion of the abutment. Above this, colluvium is present. A core recovery of 30% covers the bedrock. Three holes were drilled in the left abutment. Core recovery in LA-1 and LA-3 was 34% and 50% respectively. In hole LA-2, core recovery was 74%. In LA-2 was 97% exclusive of overburden.	Estimated for a section of the left abutment. Right Abutment -- American section: 6' of loose rock and soil? of bedrock. Previous section: 5' of soil, loose rock and roots. Channel section -- American section: 1-2' to shape and clean out shale layers. Left Abutment -- American section: 10' of soil, loose rock and 3' of weathered rock. Previous section: 10' of soil and root zone.	An around and around section was needed on the right abutment nose. Lining will be required since the section is erode. The depth to sound sandstone and shale is 10' or less.	I may be available from within a 3 mi. radius available at mouth of Bushall Creek and at Van Ardale and at Van Ardale downstream, 11 mi. AF & RR-Local bedrock may be suitable but shale should be removed. Some sandstone and shale could be used.	Low to Moderate. Rockfill, earth and concrete.	Further studies needed on stability and suitability of construction materials.		

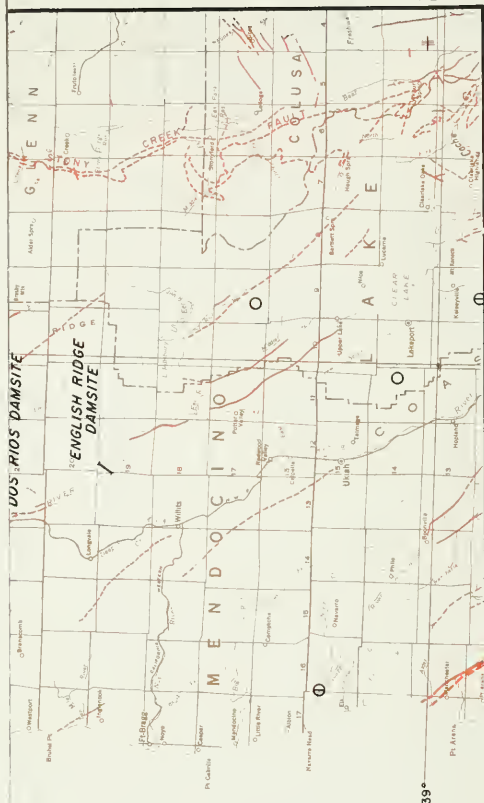
TABLE 9 (continued)

Location number	Site name	Stream	Foundation conditions	Striping	Spillway	Diversion tunnel	Construction materials	Settled city	Feasible structures	Special problems
E 1/2 Sec. 13, T114N, R90W	Remore	Bel River	The foundation is underlain by greenstone, sandstone and slate of the Franciscan formation. These rocks are highly jointed and may be mass or jointed. No faults are apparent.	Estimated for a 400' high rockfill or concrete dam. Right abutment -- Impervious section: 20'. Previous section: 15'. Channel section -- Impervious section: 2' to shape. Previous section: Left abutment -- Impervious section: 20'. Previous section: 15'.	A glory hole spillway is recommended. A spillway is also feasible through a saddle left abutment.	A diversion tunnel through the left abutment will be mostly in greenstone.	Valley fill and terrace fill in the Valley 1-1/2 mi. northeast. P-River gravels in the Bel River below Scott Dam. NP Quarries in greenstone within a 1/2 mi. radius.	Moderate Rockfill or concrete dam.		









LEGEND

FAULTS

- ACTIVE FAULTS (AFTER C. F. RICHTER)
- OTHER FAULTS, ACTIVITY NOT ASCERTAINED
- APPROXIMATELY LOCATED OR CONCEALED FAULT

EARTHQUAKE EPICENTERS

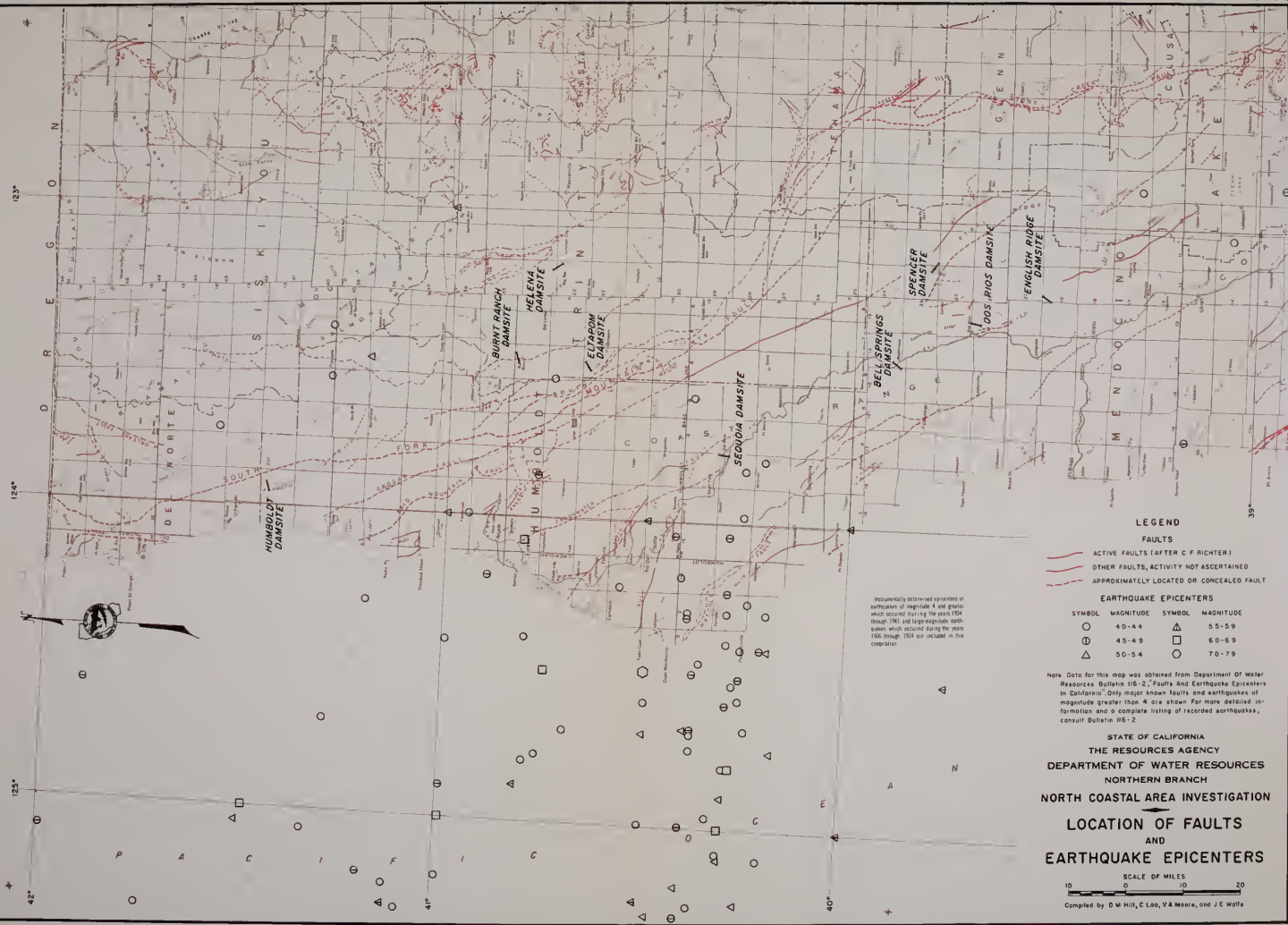
SYMBOL	MAGNITUDE	SYMBOL	MAGNITUDE
○	4.0-4.4	△	5.5-5.9
⊙	4.5-4.9	□	6.0-6.9
△	5.0-5.4	⊙	7.0-7.9

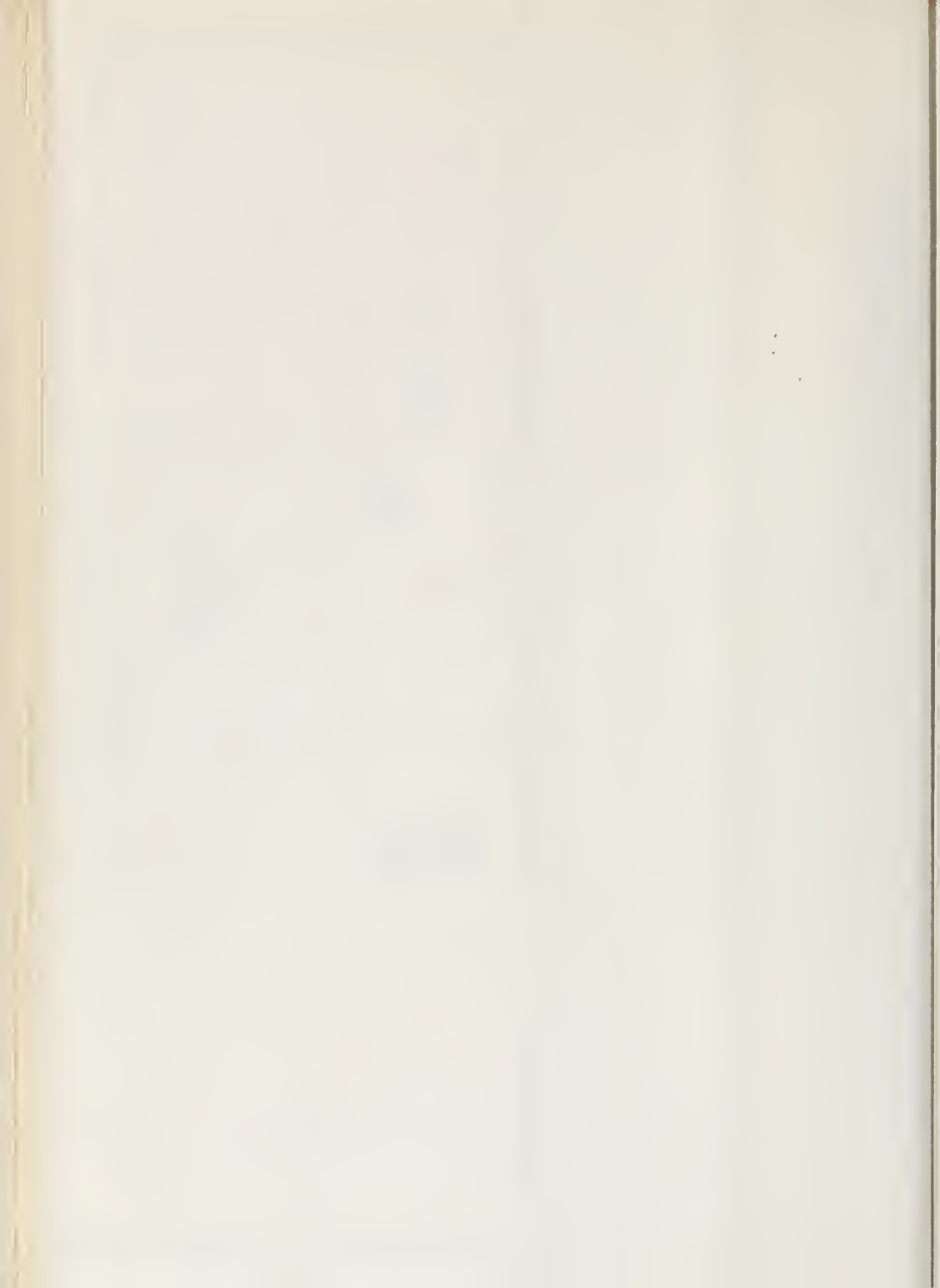
Note: Data for this map was obtained from Department of Water Resources Bulletin 116-2, "Faults and Earthquake Epicenters in California". Only major known faults and earthquakes of magnitude greater than 4 are shown. For more detailed information and a complete listing of recorded earthquakes, consult Bulletin 116-2.

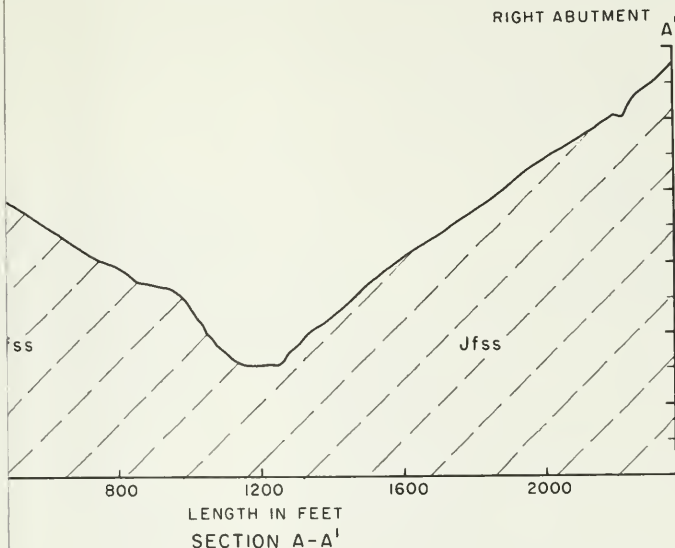
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
LOCATION OF FAULTS
AND
EARTHQUAKE EPICENTERS



Compiled by O M Hill, C. Lao, V A Moore, and J E Wolfe







LEGEND





SURFICIAL DEPOSITS

- al STREAM ALLUVIUM - SAND AND GRAVEL
- sw COLLUVIUM - DEEP TALUS AND LANDSLIDE DEBRIS

FRANCISCAN GROUP

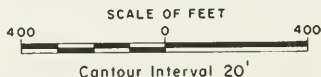
- ss SANDSTONE - GENERALLY MASSIVE, FINE TO COARSE GRAINED.
- sh SHALE - INTERBEDDED WITH SANDSTONE, GENERALLY INTENSELY SHEARED AND FRACTURED.
- fc CHERT - THINLY BEDDED WITH SHALE PARTINGS.
- gs GREENSTONE - DENSE DARK ALTERED VOLCANIC ROCK.

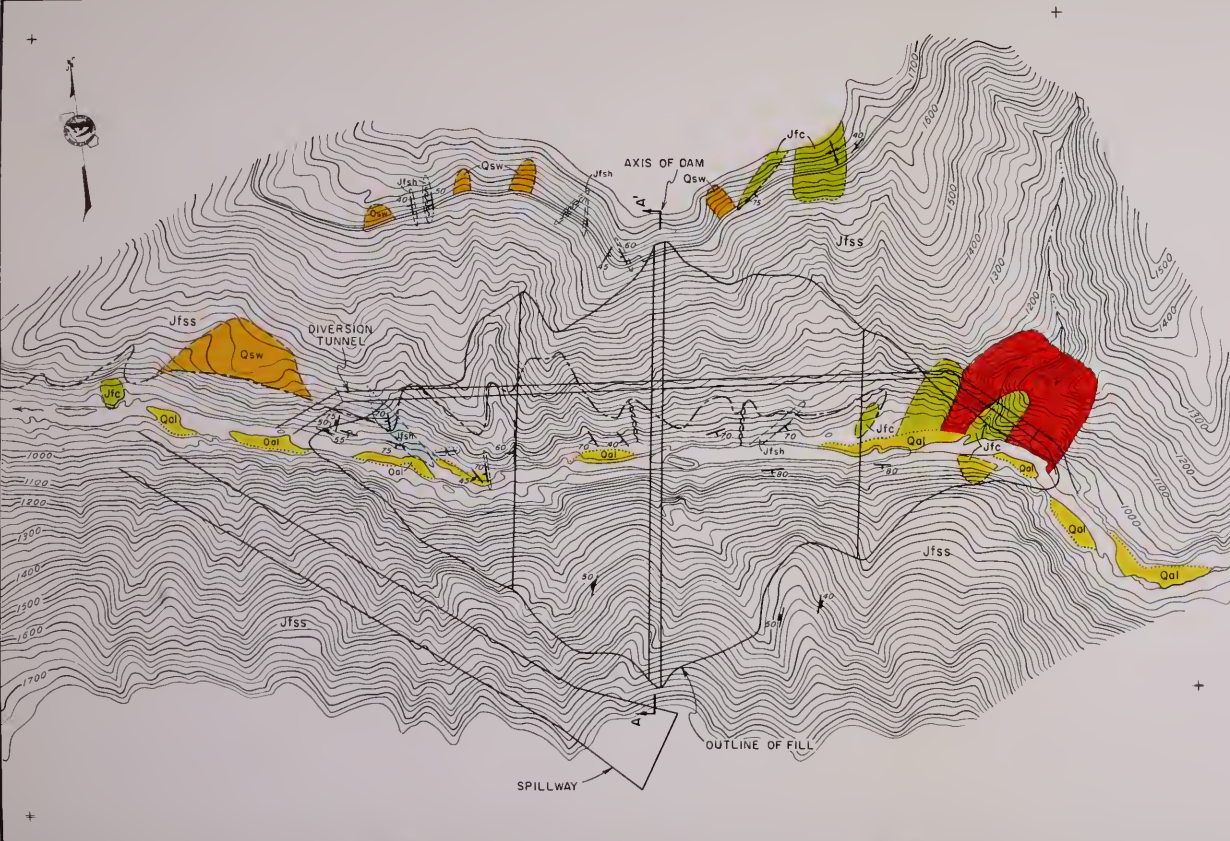
SYMBOLS

- BEDDING  MINOR FOLDS SHOWING DIRECTION OF PLUNGE
- VERTICAL BEDDING  GEOLOGIC CONTACT - DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE INFERRED OR CONCEALED
- JOINTS  LIMIT OF NEARLY CONTINUOUS BEDROCK EXPOSURES
-  GEOLOGIC SECTION LINE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION DOS RIOS DAMSITE - M FK EEL RIVER





- LEGEND**
- SURFICIAL DEPOSITS**
- RECENT**
- Qol** STREAM ALLUVIUM - SAND AND GRAVEL
 - Qsw** COLLUVIUM - DEEP TALUS AND LANDSLIDE DEBRIS
- FRANCISCAN GROUP**
- Jfss** SANDSTONE - GENERALLY MASSIVE, FINE TO COARSE GRAINED.
 - Jfsh** SHALE - INTERBEDDED WITH SANDSTONE, GENERALLY INTENSELY SHEARED AND FRACTURED.
 - Jfc** CHERT - THINLY BEDDED WITH SHALE PARTINGS.
 - Jt** GREENSTONE - DENSE DARK ALTERED VOLCANIC ROCK.
- SYMBOLS**
- 70 STRIKE AND DIP OF BEDDING
 - 30 STRIKE AND DIP OF VERTICAL BEDDING
 - 30 STRIKE AND DIP OF JOINTS
 - MINOR SHEAR ZONES
 - 40 MINOR FAULTY SHOWING DIRECTION DIP
 - MINOR FOLDS SHOWING DIRECTION OF PLUNGE
 - GEOLOGIC CONTACT - DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE INFERRED OR CONCEALED
 - LIMIT OF NEARLY CONTINUOUS BEDROCK EXPOSURES
 - GEOLOGIC SECTION LINE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTION
OOS RIOS DAMSITE-M FK EEL RIVER

SCALE OF FEET
0 400
Contour Interval 20'



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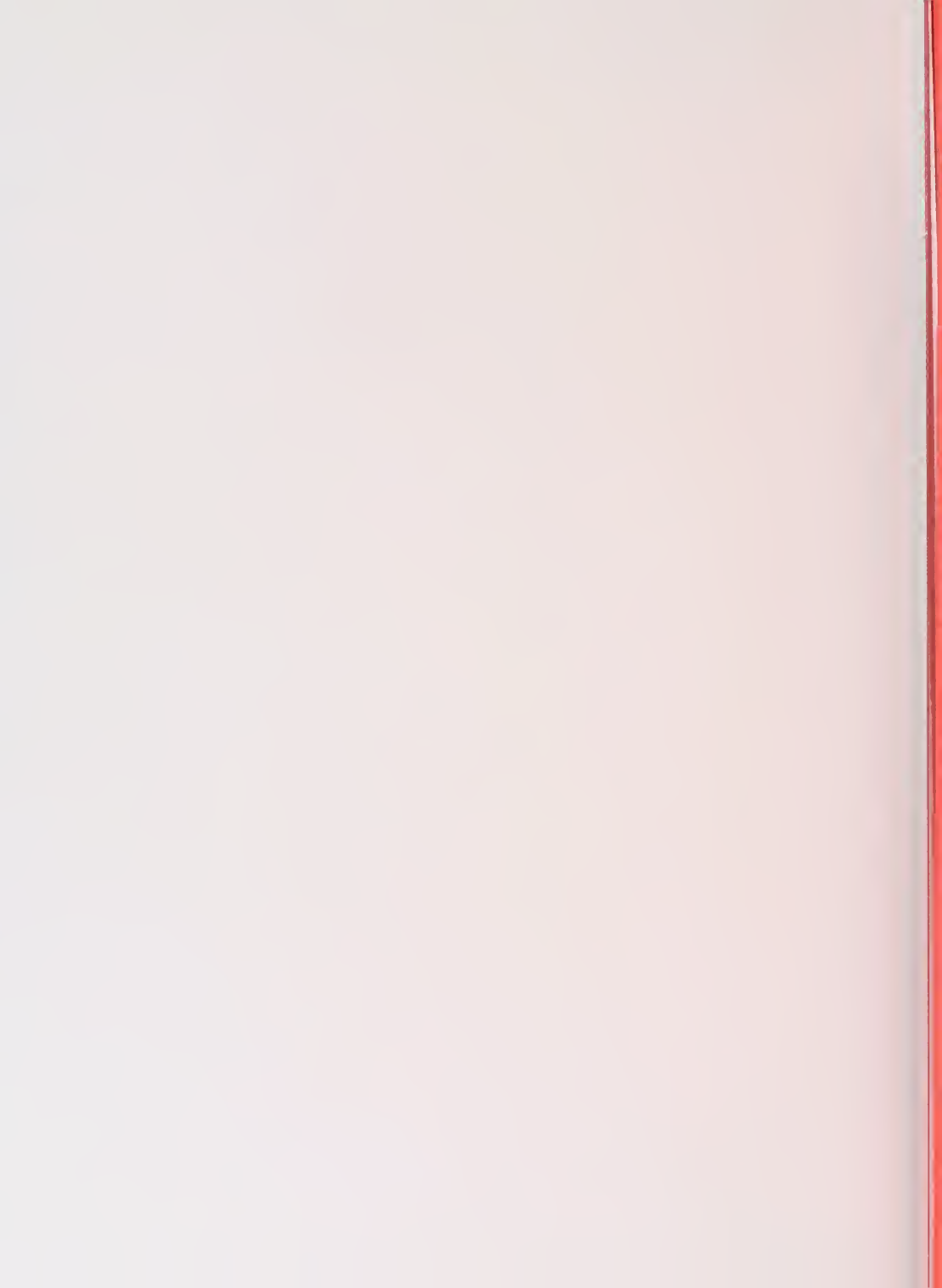
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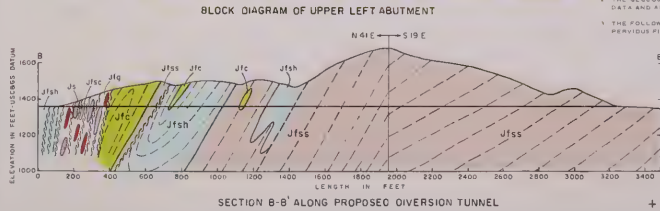
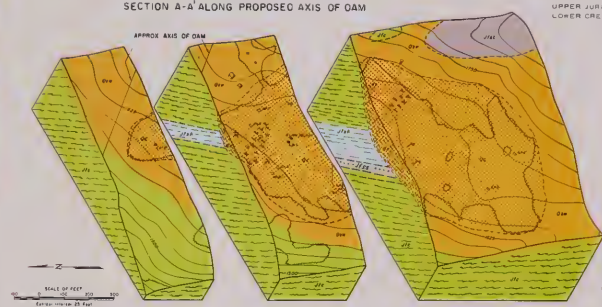
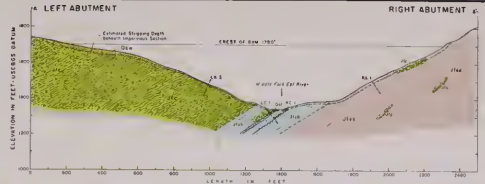
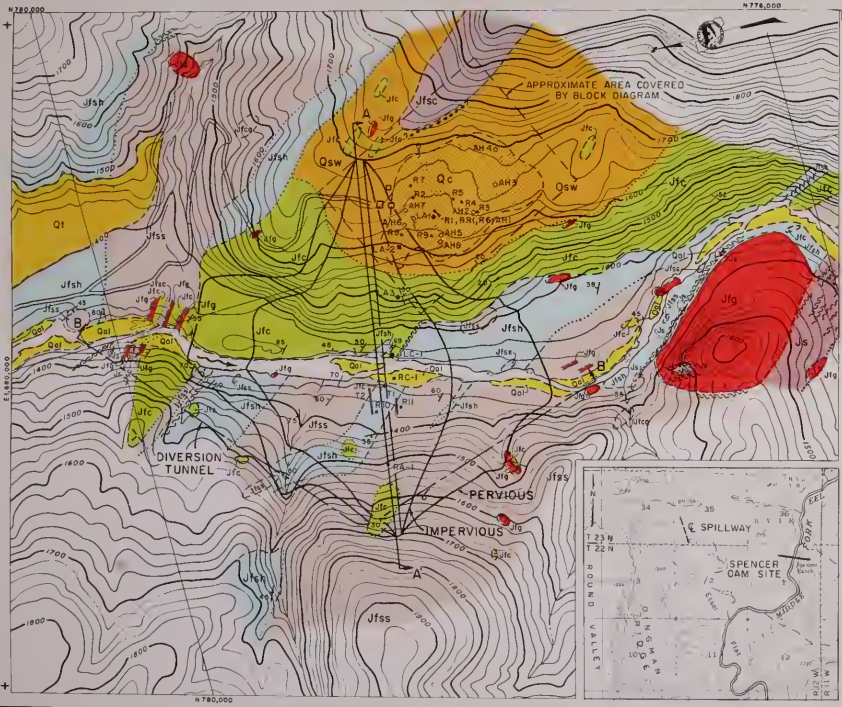
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- LEGEND**
- QUATERNARY UNCONSOLIDATED DEPOSITS**
- Qal RECENT ALLUVIUM - CONSISTING OF CHANNEL SAND AND GRAVEL BARS.
 - Qsw RECENT SLOPE WASH - CONSISTING OF FINE-GRAINED SOILS GENERALLY UNDERLAIN BY CHERT AND SHALEY CHERT.
 - Qc CLAY - LOW STRENGTH, CONTAINS BLOCKS AND FRAGMENTS OF HARD ROCK.
 - Ql RECENT TERRACE DEPOSIT - GRAVEL, SAND AND SILT.
- QUATERNARY**
- FRANCISCAN GROUP**
- Jfss SANDSTONE - GENERALLY MASSIVE, FINE TO COARSE GRAINED.
 - Jfc CHERT - THIN BEDDED WITH SHALE PARTINGS, CONTORTED, VARIOUSLY COLORED RANGING THROUGH GREEN, RED, AND WHITE.
 - Jfsh SHALE - GENERALLY HEAVILY SHEARED AND CONTORTED.
 - Jfcg CONGLOMERATE LENSES - IN SANDSTONE.
 - Jfg GREENSTONE - ALTERED BASIC VOLCANIC ROCKS BOTH INTRUSIVE AND EXTRUSIVE.
 - Js SERPENTINE - INTRUSIVE FRANCISCAN ROCKS - GENERALLY HEAVILY SHEARED AND CONTORTED.
 - Jfsc GLAUCOPHANE SCHIST AND RELATED SCHISTOSE ROCKS.
- SYMBOLS**
- LA-6 VERTICAL DIAMOND DRILL HOLE.
 - AM3 INCLINED DRILL HOLE SHOWING DIRECTION.
 - RS AUGER DRILL HOLE.
 - RS RESISTIVITY SURVEY POINT.
 - 30 ATTITUDE OF INCLINED REG.
 - 30 APPROXIMATE OR SLUMPED ATTITUDE.
 - 30 INFERRED FAULT.
 - 30 SHEAR ZONE.
 - 30 GEOLOGIC CONTACT - DASHED WHERE APPROXIMATE, DOTTED WHERE COVERED OR INFERRED.
 - 30 SPRING.
 - 30 GEOLOGIC SECTION.
 - 30 EXPLORATORY TRENCH.
- NOTES**
1. TOPOGRAPHY BASE IS PRELIMINARY DEPARTMENT OF WATER RESOURCES MAP, DATED 1958.
 2. THE GEOLOGIC SECTIONS ARE DRAWN FROM SURFICIAL MAPPING AND LIMITED SUBSURFACE EXPLORATION DATA AND ARE THEREFORE DIAGRAMATIC IN PART.
 3. THE FOLLOWING EMBANKMENT SLOPES WERE USED: IMPERVIOUS FILL UPSTREAM - 2:1, DOWNSTREAM - 1:1; PERVIOUS FILL UPSTREAM - 3:1, DOWNSTREAM - 2:1.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTIONS
SPENCER DAM SITE - M FK EEL RIVER
SCALE OF FEET
0 400
Contour Interval 20



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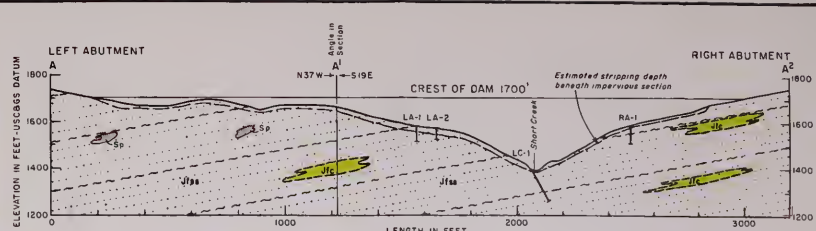
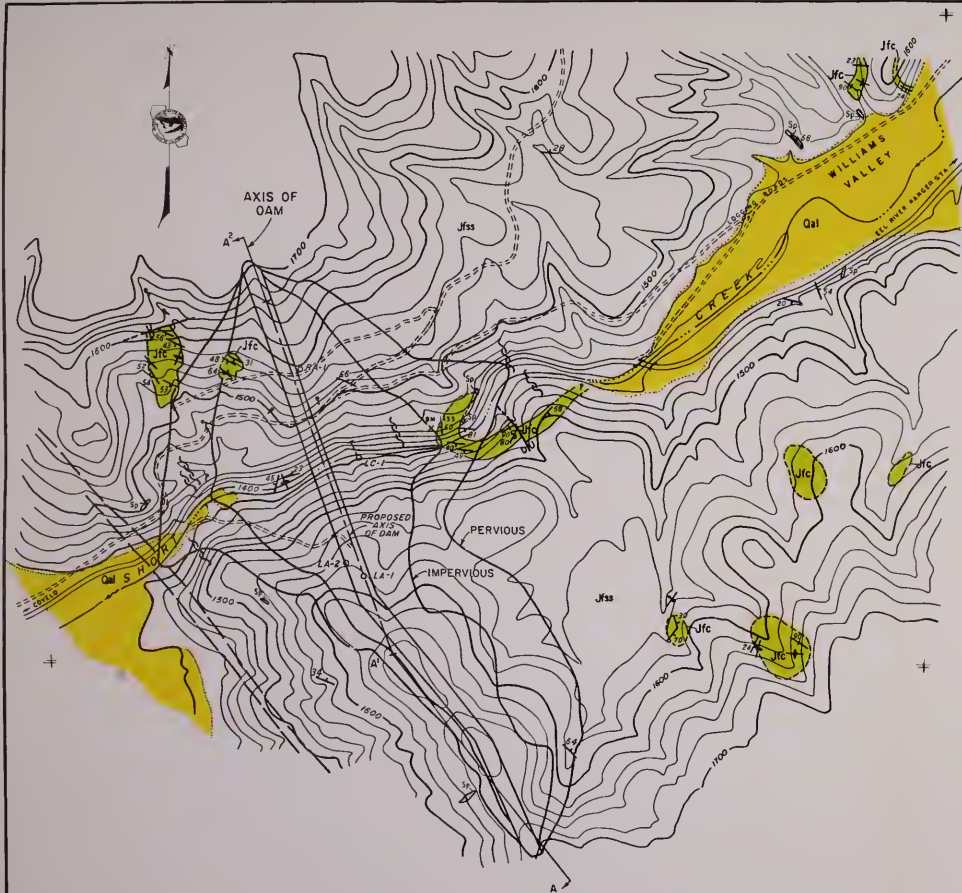
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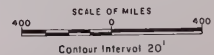


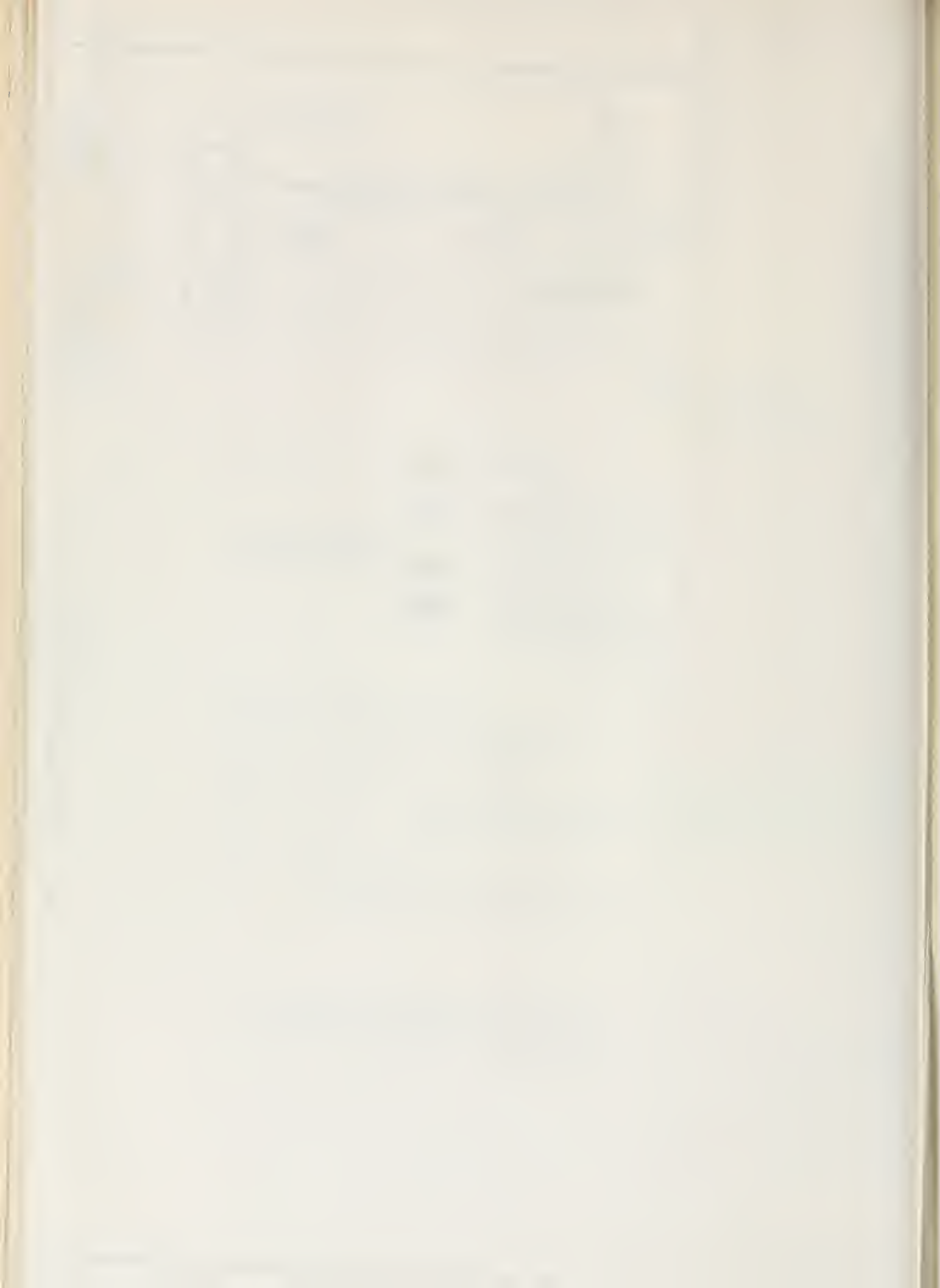
- LEGEND**
- QUATERNARY**
- Qal** ALLUVIUM
UNCONSOLIDATED STREAM DEPOSIT AND VALLEY FILL
 - Jfss** FRANCISCAN SANDSTONE
QUARTZ LITHIC GRAYWACKE, MASSIVE, WELL INDURATED, MODERATELY FRACTURED, CONTAIN BEDS TOO THIN TO MAP OF BLACK SLATY-SHALE.
 - Jfc** FRANCISCAN-CHERT
WELL BEDDED, SOMEWHAT CONTORTED
 - Sp** FRANCISCAN SERPENTINE
DARK GREEN, OFTEN TALCOSE, SHEARED; OFTEN SURROUNDED BY HYDROTHERMALLY ALTERED ZONES.

- SYMBOLS**
- 25° STRIKE AND DIP OF BEDS
 - 70° STRIKE AND DIP OF OVERTURNED BEDS
 - 90° STRIKE AND DIP OF VERTICAL BEDS
 - ANTICLINE
 - SYNCLINE
 - ALLUVIAL CONTACT
 - LITHOLOGIC CONTACT - DASHED WHERE APPROXIMATELY LOCATED
 - FAULT - DASHED WHERE APPROXIMATELY LOCATED
 - SHEAR ZONE
 - SPRING
 - OR-1 VERTICAL CORE HOLE
 - LC-1 INCLINED CORE HOLE, SHOWING BOTTOM LOCATION
 - A-A' GEOLOGIC SECTION LINE

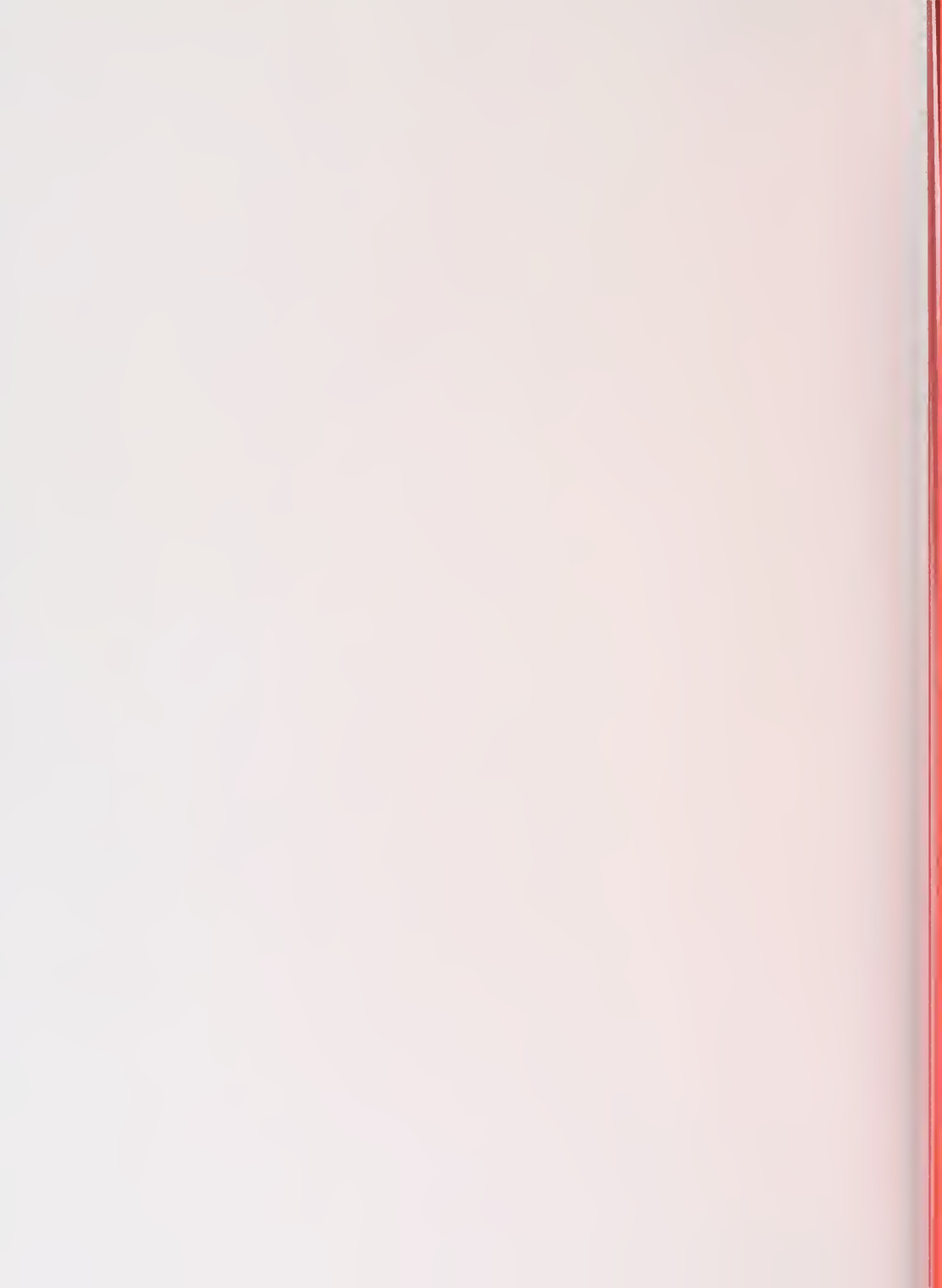
NOTES: THE FOLLOWING EMBANKMENT SLOPES WERE USED:
IMPERVIOUS FILL UPSTREAM=1.75:1; DOWNSTREAM=1.5:1
PERVIOUS FILL UPSTREAM=3:1; DOWNSTREAM=2.5:1

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTION
FRANCISCAN DAMSITE - SHORT CREEK

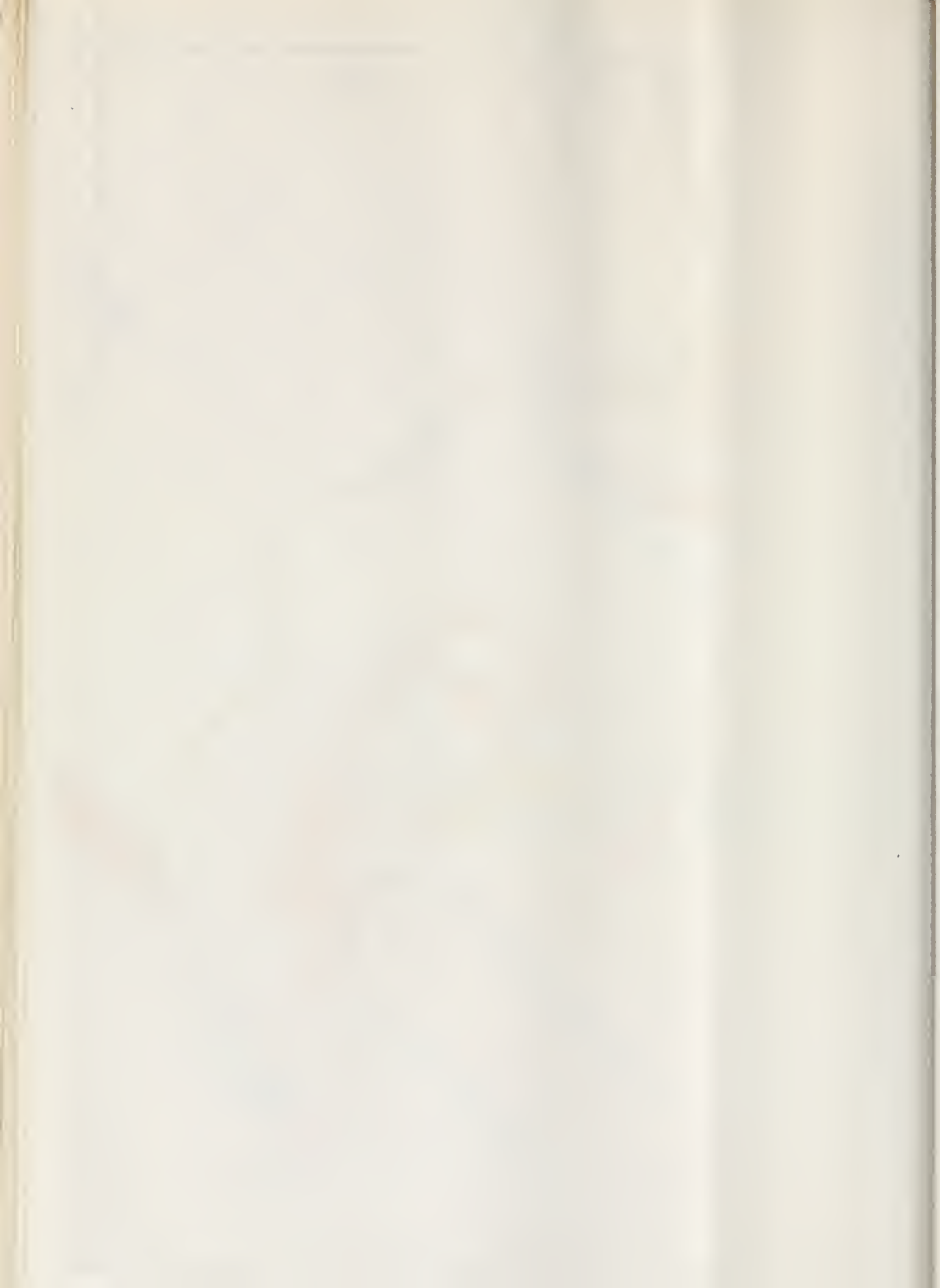


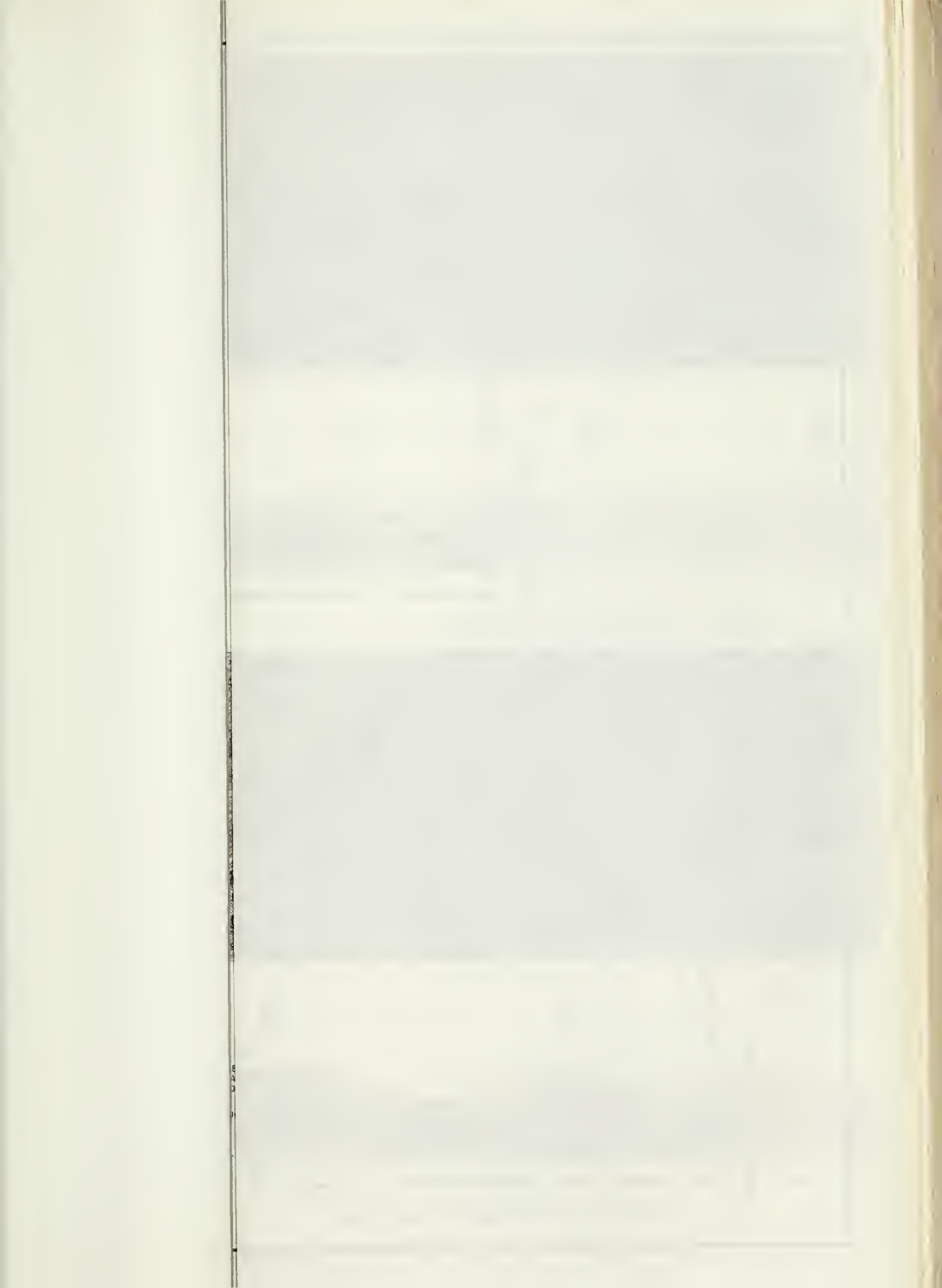


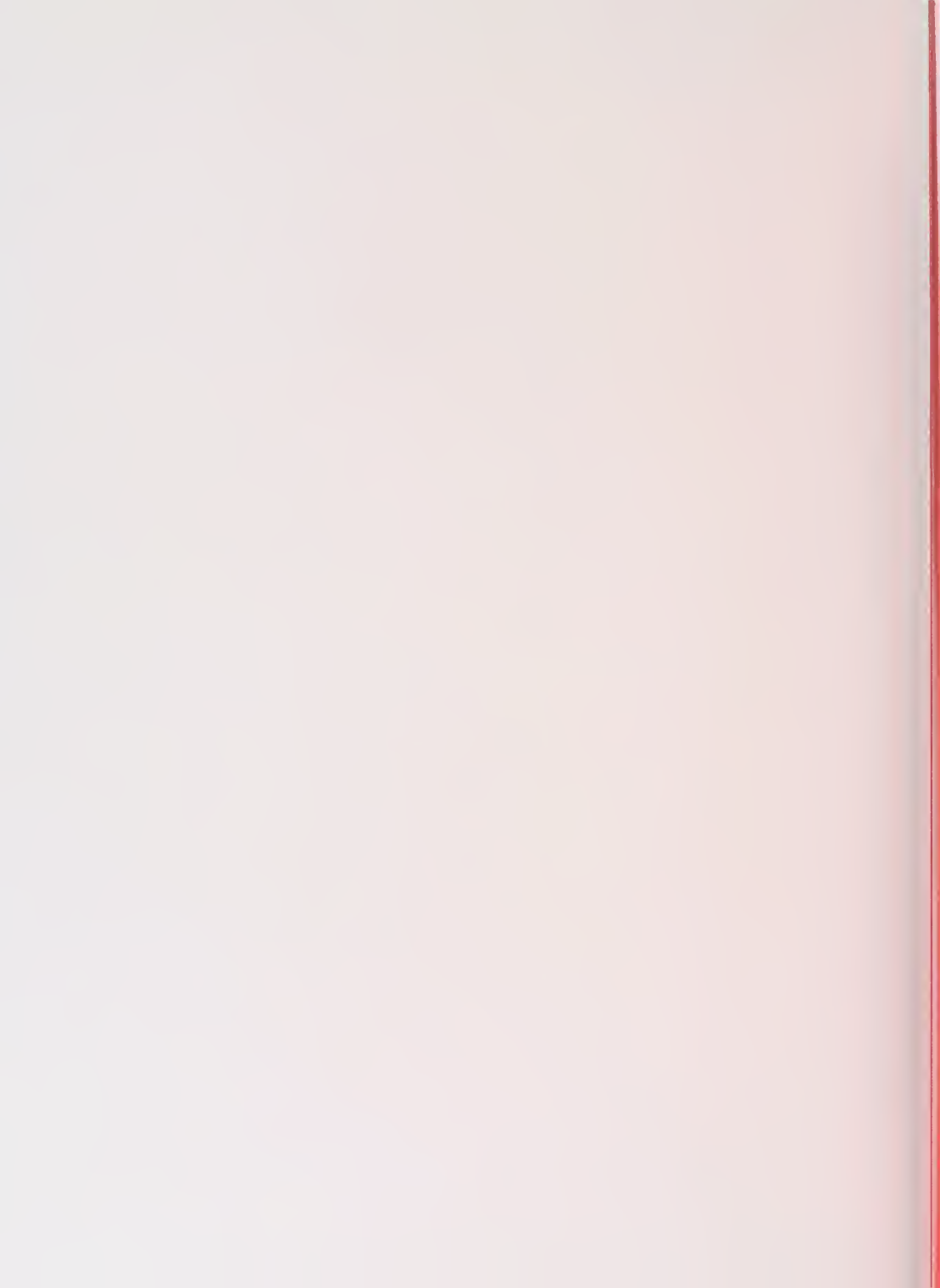
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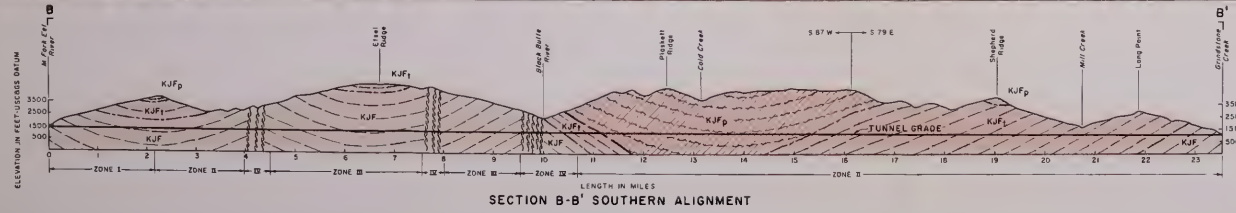
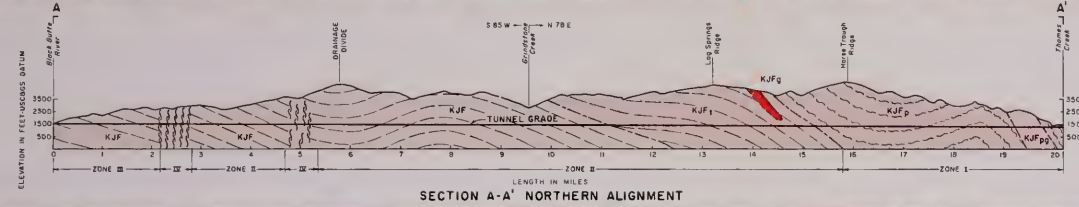
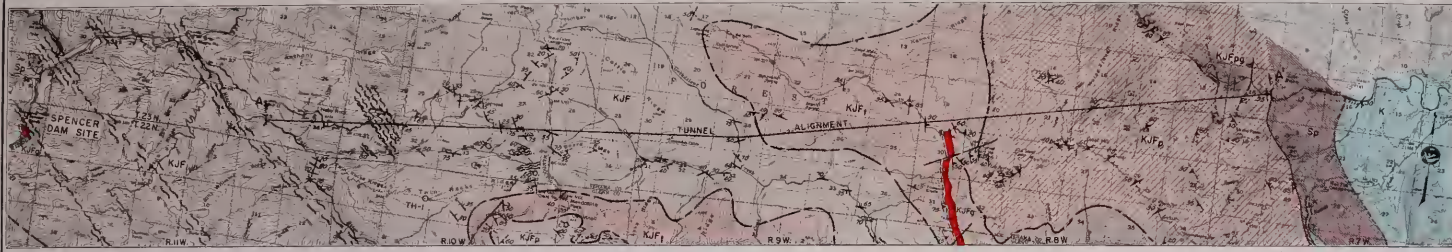












- LEGEND**
- KJf** FRANCISCAN - PREDOMINANTLY SHALE AND SANDSTONE. ALL UNITS HAVE SUFFERED CONSIDERABLE WEARING AND ARE EXTENSIVELY FOLDED AND FAULTED. LESS IMPORTANT UNITS INCLUDE CONGLOMERATE, GREENSTONE, CHERT AND LIMESTONE.
 - KJf1** TRANSITIONAL FRANCISCAN - SLIGHTLY METAMORPHOSED EQUIVALENTS OF KJf. SLATE AND SLATTY SHALE ALONG WITH PHYLLITE AND SLATTY GREENSTONE SANDSTONE ARE THE MOST PROMINENT UNITS. GREENSTONE, CHERT AND CONGLOMERATE FORM THE REMAINDER OF THIS GROUP OF ROCKS.
 - KJfP** PLASKETT - MODERATELY METAMORPHOSED EQUIVALENTS OF KJf. ALL ROCKS HAVE SUFFERED CONSIDERABLE REGIONAL DEFORMATION AND ARE EXTENSIVELY FOLDED AND WRIRLED. THE INCREASE IN METAMORPHIC GRADE HAS PRODUCED OVERALL A MORE COMPETENT GROUP OF ROCKS THAN THE PARENT MATERIAL. BEDDING TYPES INCLUDE PHYLLITE, QUARTZITIC SCHIST, SCHISTOSE SANDSTONE AND SLATE. TWO LARGE BODIES OF FOLIATED GREENSTONE WERE MAPPED WITHIN THE PLASKETT UNIT.
 - KJfQ** GREENSTONE - DENSE, HARD ALTERED VOLCANIC ROCK. GREENSTONE IS FOUND THROUGHOUT THE AREA MAPPED USUALLY IN SMALL DISCONTINUOUS MASSES.
 - K** FOLIATED GREENSTONE - GREENSTONE WITHIN THE PLASKETT UNIT, REPRESENTING METAMORPHOSED EQUIVALENTS OF FRANCISCAN GREENSTONE. THE ROCK IS GENERALLY HARD AND DENSE BUT SHOWS CONSIDERABLE SCHISTOSITY OR FOLIATION.
 - Sp** SERPENTINE - INTENSELY FRACTURED TO COMPLETELY CRUSHED SERPENTINIZED ULTRABASIC ROCKS.

- TUNNELING CONDITIONS ZONES**
(SHOWN ON GEOLOGIC SECTIONS)
- ZONE I** INCLUDES ROCKS OF THE PLASKETT UNIT AND ESPECIALLY COMPETENT PORTIONS OF THE FRANCISCAN AND TRANSITIONAL FRANCISCAN UNITS. THE ROCK IS SCHISTOSE OR STRATIFIED AND IS MODERATELY BLOCKY AND SEAMY.
 - ZONE II** INCLUDES ROCKS OF THE TRANSITIONAL FRANCISCAN UNIT AND LARGE PORTIONS OF THE FRANCISCAN. THE ROCK IS STRATIFIED TO SLATTY, MODERATELY TO INTENSELY FRACTURED.
 - ZONE III** INCLUDES PORTIONS OF FRANCISCAN WHERE THE SHALE SANDSTONE RAT IS HIGH AND WHERE CONSIDERABLE SHEARING WAS OBSERVED. THE ROCK IS INTENSELY FRACTURED TO COMPLETELY CRUSHED.
 - ZONE IV** INCLUDES SHEAR OF FAULT ZONES AND SERPENTINE. THE ROCK IS INTENSELY SHEARED AND BRICKIATED AND IS EXPECTED TO BE MODERATELY SQUEEZING AT DEPTH.

- SYMBOLS**
- 70 STRIKE AND DIP OF BEDDING
 - VERTICAL DIP
 - 70 STRIKE AND DIP OF FOLIATION OR CLEAVAGE
 - 70 STRIKE AND DIP OF CONTORTED BEDDING
 - NOTE: UNRELIABLE ATTITUDES ARE DASHED
 - SHEAR ZONE
 - FAULT
 - THRUST FAULT
 - GEOLOGIC CONTACT
 - CONCEALED GEOLOGIC CONTACT
 - TRANSITIONAL GEOLOGIC CONTACT
 - TUNNEL ALIGNMENTS
 - LOCATION OF SPRING SAMPLES
 - LOCATION OF DIAMOND DRILL HOLES
 - GEOLOGIC SECTION LINE

NOTES

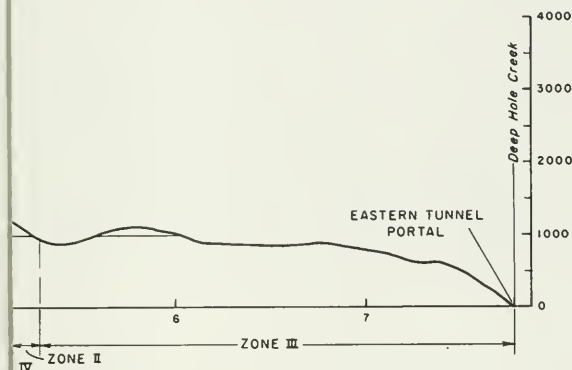
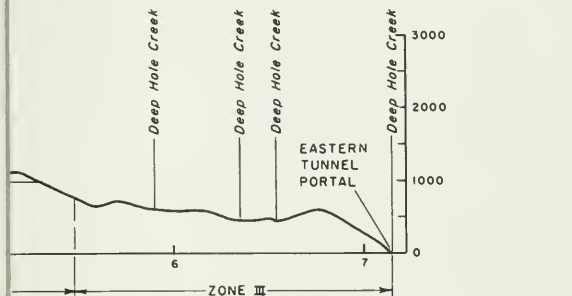
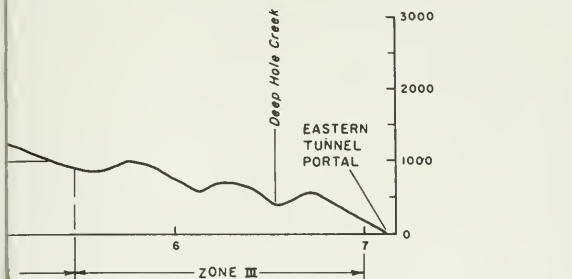
1. THIS MAP SHOWS DISTRIBUTION OF BEDROCK UNITS. RECENT ACCUMULATIONS OF ALLUVIUM, COLLUVIUM AND LANDSLIDE DEBRIS ARE OMITTED.

2. GEOLOGIC SECTIONS ARE BASED ON SURFICIAL GEOLOGIC RECONNAISSANCE WORK AND ARE DIAGNOSTIC IN PART.

CONTOUR INTERVAL 50'-100'

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
**GEOLOGIC MAP AND SECTIONS
EEL-GLINN TUNNEL**
SCALE OF MILES
0 1 2





AND FRACTURED FRANCISCAN ROCK; IN-
ED SERPENTINE AND CUT BY NUMEROUS

ROCK LOAD HP IN FEET	PERCENT OF ZONE
0.725(B+H)	50
1.1(B+H)	50

ZONE IS EXPECTED TO BE "WET HEAD-

ELYCRUSHED GOUGY FAULT ZONE MATE-
CONDITIONS AND "RUNNING GROUND"
PATED.

ROCK LOAD HP IN FEET	PERCENT OF ZONE
1.1(B+H)	75
2.1(B+H)	25

EXPECTED TO BE "WET HEADING"

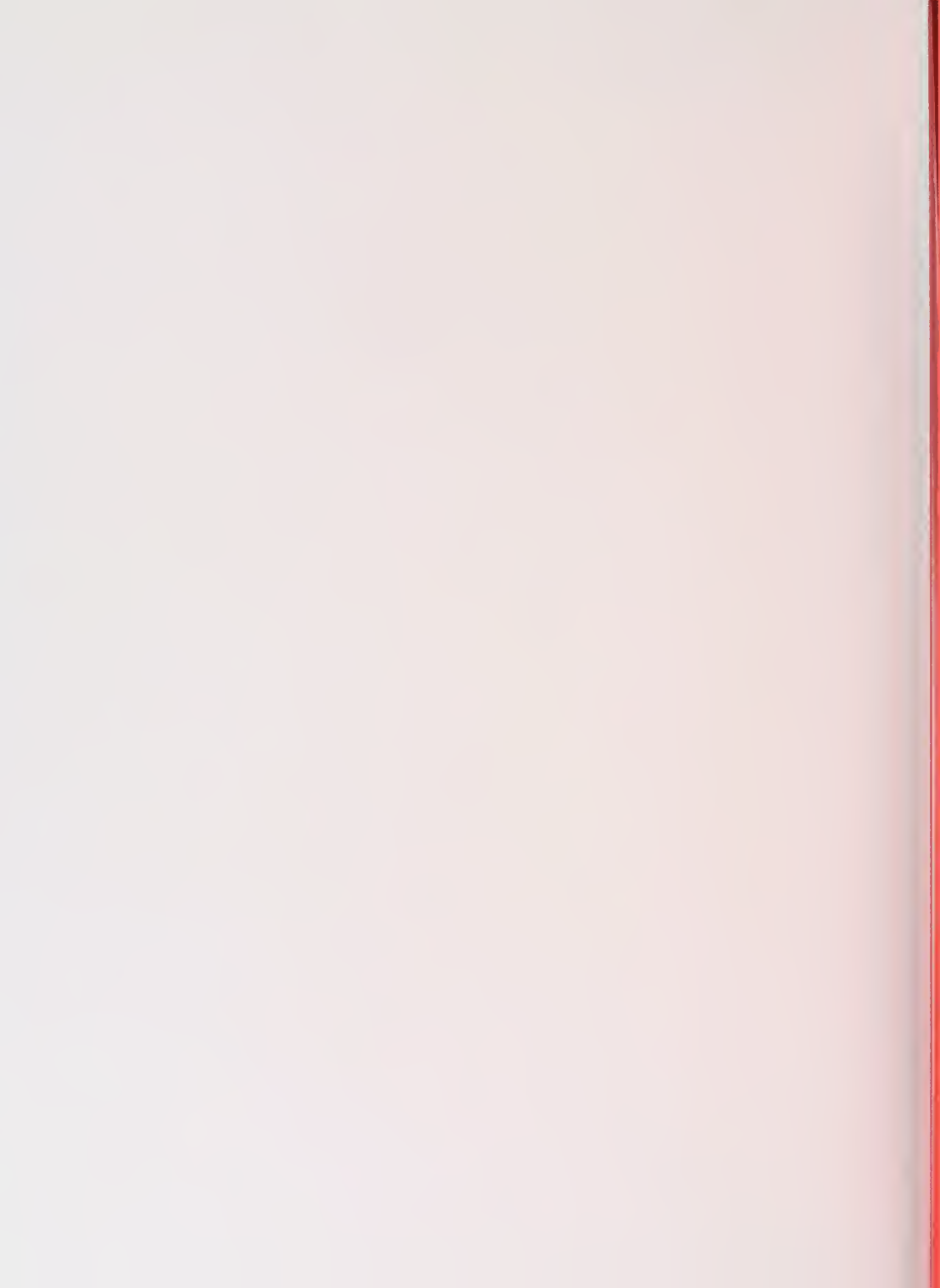
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

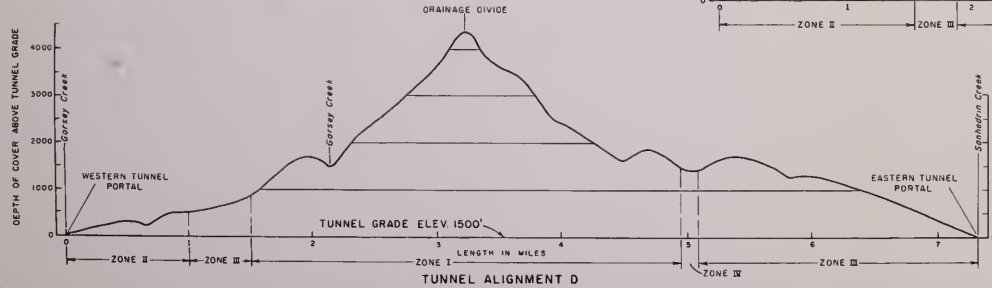
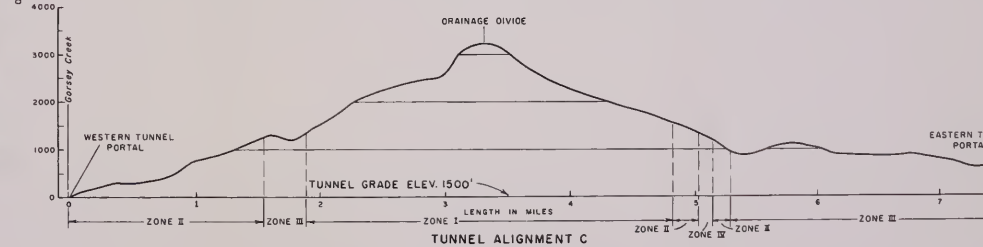
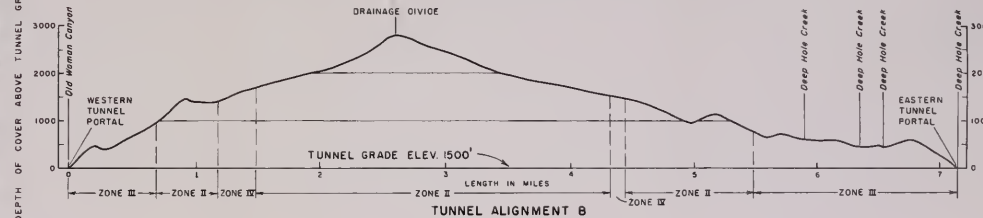
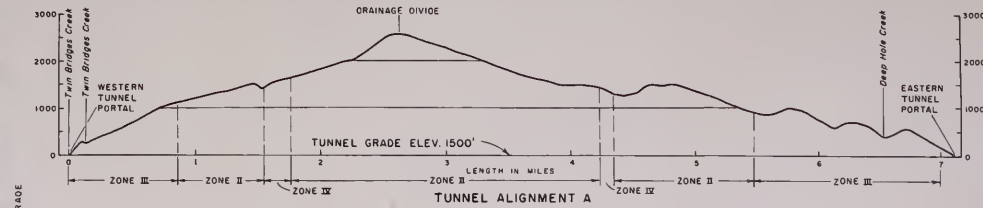
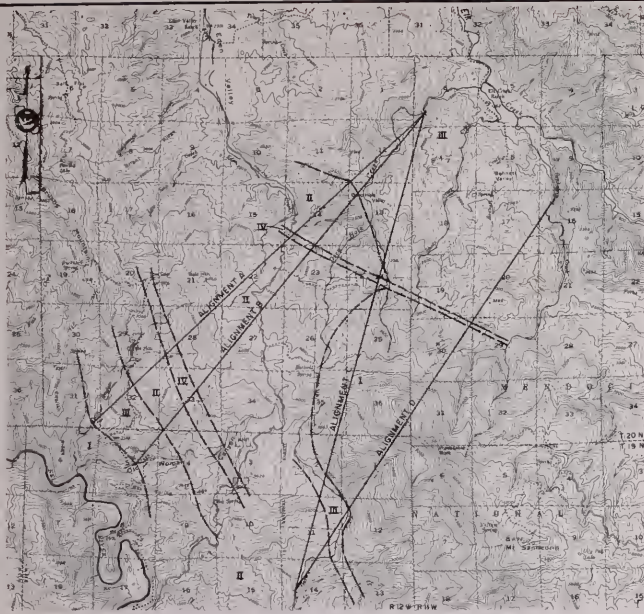
NORTH COASTAL AREA INVESTIGATION

TUNNELING CONDITIONS MAP AND SECTIONS ELK CREEK TUNNEL



Contour Interval 100'





ZONE I: SEDIMENTARY ROCK UNITS OF THE CENTRAL BELT FRANCISCAN WHICH ARE ONLY MODERATELY SHEARED & JOINTED.

ROCK CONDITION	ROCK LOAD IN HP IN FEET	PERCENT OF ZONE
MODERATELY "SLACKY" AND VERY "SLACKY" AND SLANT	0.34(18+HP)	75
VERY "SLACKY" AND SLANT	0.72(18+HP)	25

ABOUT 15% OF THIS ZONE WILL BE EXCAVATED UNDER "NET HEADING" CONDITIONS.

ZONE II: ZONE II IS SIMILAR GEOLOGICALLY TO ZONE I BUT HAS A HIGHER SHALE/LIMESTONE RATIO AND MORE CONSIDERABLY MORE SHEARING AND FRACTURING.

ROCK CONDITION	ROCK LOAD IN HP IN FEET	PERCENT OF ZONE
VERY "SLACKY" AND SLANT	0.72(18+HP)	50
COMPLETELY CRUSHED	1.10(18+HP)	10

ABOUT 15% OF ZONE II WILL BE "NET HEADING" TUNNELING

ZONE III: SHEARED AND FRACTURED FRANCISCAN ROCK, INTERRUPTED BY CRUSHED SERPENTINE AND CUT BY NUMEROUS FAULTS.

ROCK CONDITION	ROCK LOAD IN HP IN FEET	PERCENT OF ZONE
VERY "SLACKY" AND SLANT	0.72(18+HP)	50
COMPLETELY CRUSHED	1.10(18+HP)	50

ABOUT 35% OF THIS ZONE IS EXPECTED TO BE "NET HEADING" TUNNELING.

ZONE IV: COMPLETELY CRUSHED ODOGY FAULT ZONE MATERIAL. "SLACKY" CONDITIONS AND "RUNNING GROUND" SHOULD BE ANTICIPATED.

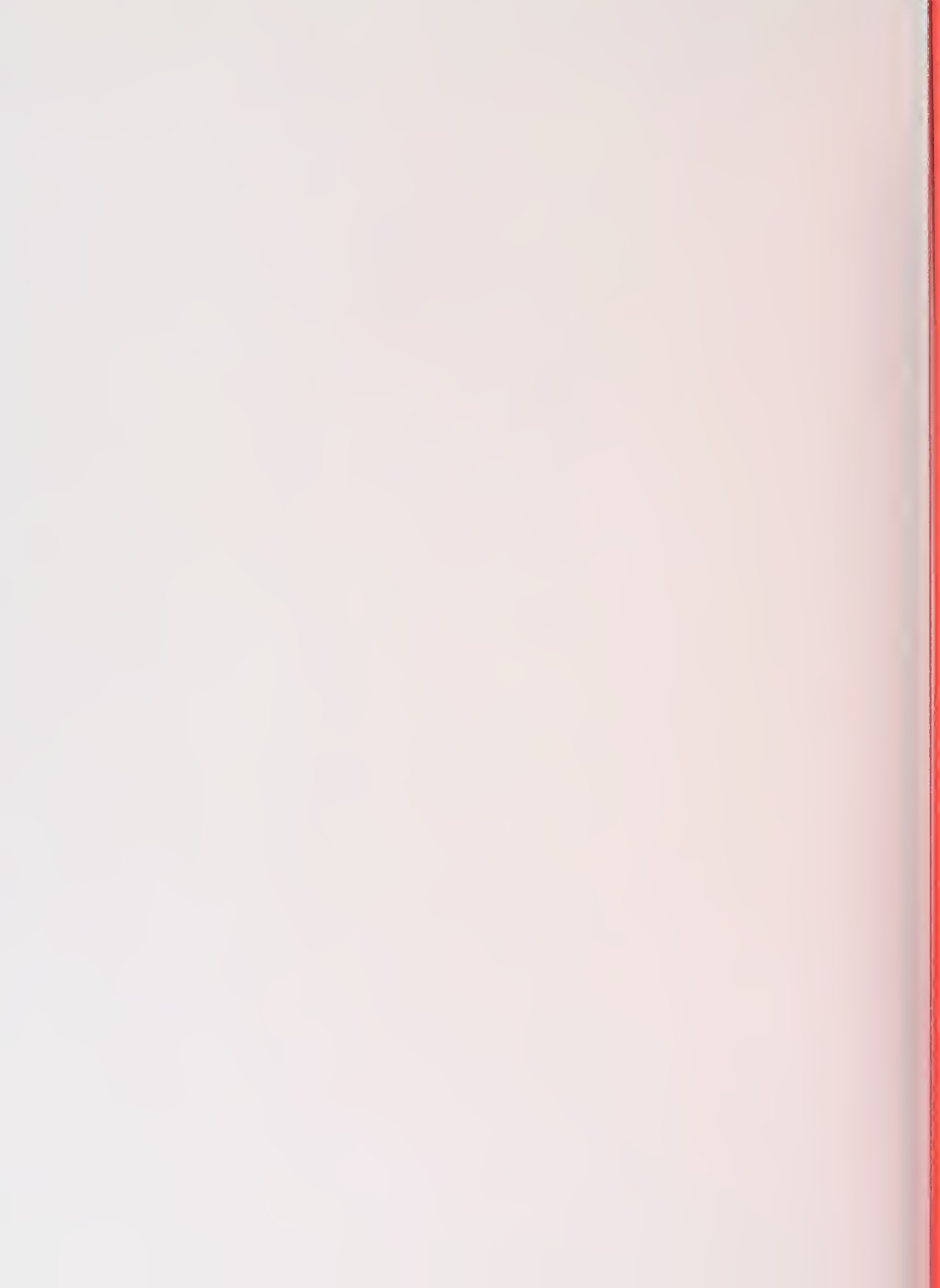
ROCK CONDITION	ROCK LOAD IN HP IN FEET	PERCENT OF ZONE
COMPLETELY CRUSHED	1.10(18+HP)	75
MODERATELY CRUSHED ROCK	2.10(18+HP)	25

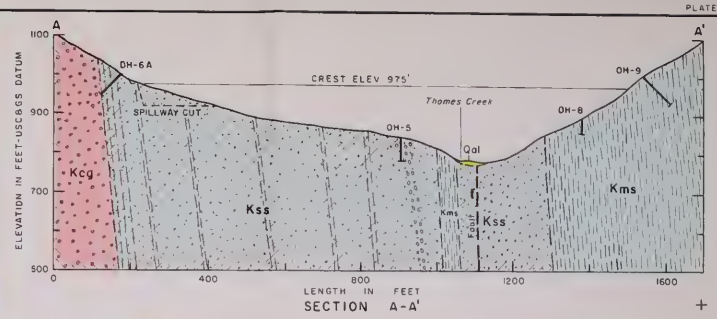
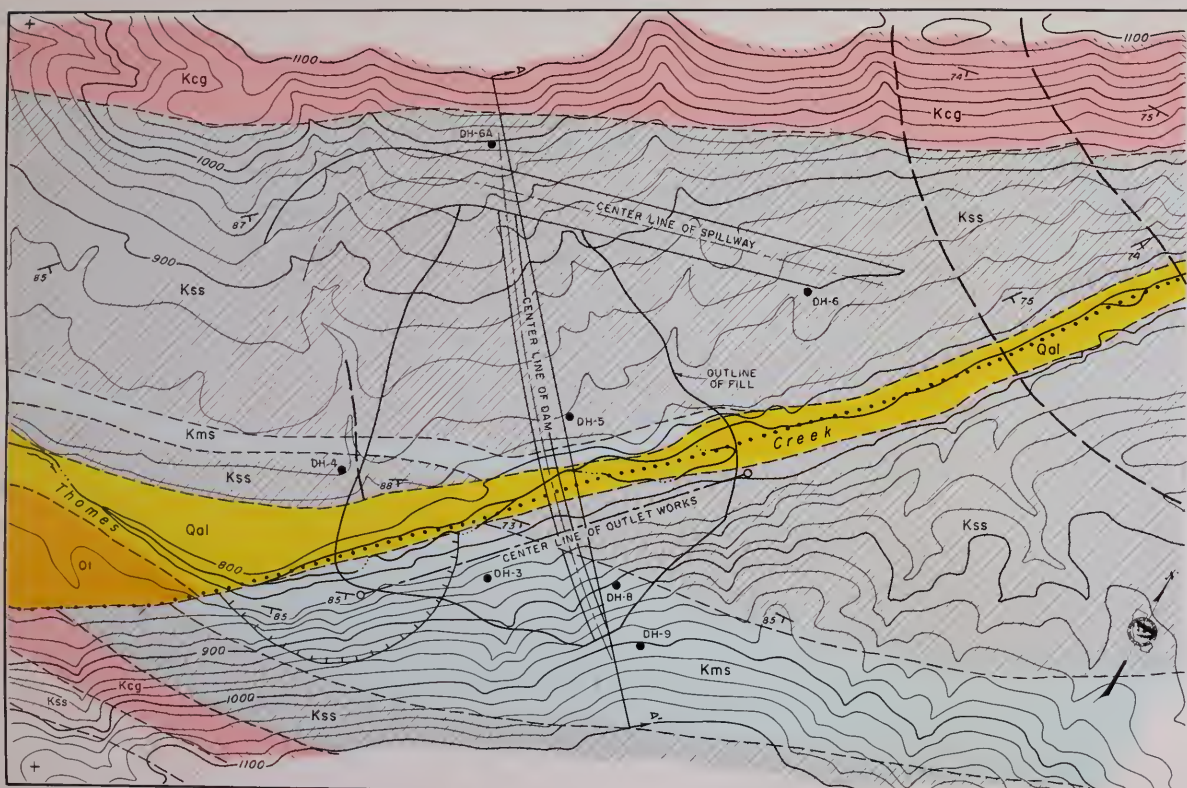
50% OF ZONE IV IS EXPECTED TO BE "NET HEADING" TUNNELING.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
TUNNELING CONDITIONS MAP AND SECTIONS
ELK CREEK TUNNEL
SCALE OF MILES
0 1 2
Contour Interval 100'









- LEGEND**
- Qal** STREAM CHANNEL DEPOSITS
UNCONSOLIDATED SAND AND GRAVEL
 - Q1** TERRACE DEPOSITS
UNCONSOLIDATED SILT WITH SAND AND GRAVEL
 - Kms** MUOSTONE
INCLUDES A FEW THIN SANDSTONE BEDS
 - Kss** SANDSTONE
INCLUDES OCCASIONAL THIN INTERBEDS
OF MUOSTONE AND CONGLOMERATE
 - Kcg** CONGLOMERATE
GENERALLY IN THICK MASSIVE BEDS
WITH OCCASIONAL INTERBEDS OF MUOSTONE

- SYMBOLS**
- 75°** STRIKE AND DIP OF BEDS
 - DH-6** DIAMOND DRILL HOLE LOCATION
 - - -** GEOLOGIC CONTACT - DASHED WHERE
INFERRED OR APPROXIMATELY LOCATED
 - - -** FAULT - DASHED WHERE INFERRED
OR APPROXIMATELY LOCATED,
DOTTED WHERE CONCEALED
 - A A'** GEOLOGIC SECTION LINE
 - ~** LANDSLIDE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTION
PASKENTA DAMSITE - THOMES CREEK
SCALE OF FEET
0 200
Contour Interval 20'





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LEGEND

SOURCE OF IMPERVIOUS AND
SEMI-PERVIOUS MATERIAL

SOURCE OF PERVIOUS MATERIAL

QUARRY AREA - SOURCE OF ROCK-
FILL AND /OR RIPRAP MATERIAL

BORROW AREA



AUGER HOLE LOCATION AND NUMBER

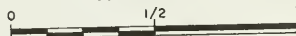
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STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION






 LOCATION OF CONSTRUCTION MATERIALS
 PASKENTA DAMSITE - THOMES CREEK

SCALE OF MILES



Contour Interval 50'



- LEGEND
-  SOURCE OF IMPERVIOUS AND SEMI-PERVIOUS MATERIAL
 -  SOURCE OF PERVIOUS MATERIAL
 -  QUARRY AREA - SOURCE OF ROCK-FILL AND/OR RIPRAP MATERIAL
 -  BORROW AREA
 -  AUGER HOLE LOCATION AND NUMBER

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

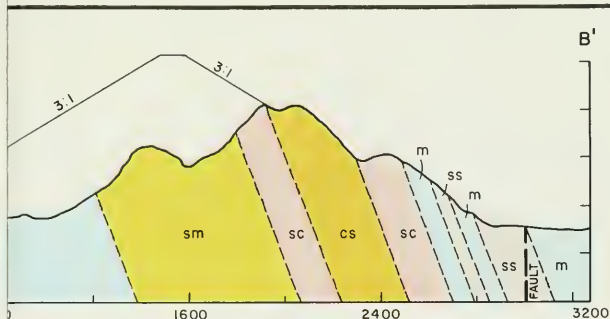
NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
PASKENTA DAMSITE-THOMES CREEK

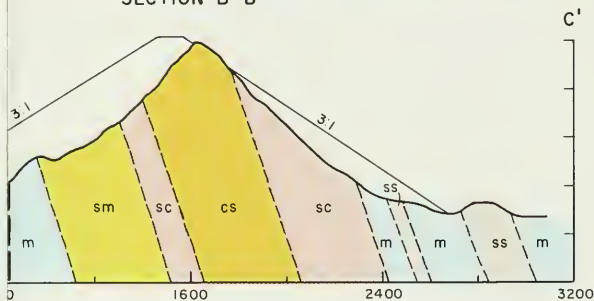
SCALE OF MILES
1/2

Contour Interval 50'





SECTION B-B'



SECTION C-C'

LEGEND

- SAND AND GRAVEL
- TS — MOSTLY SILT, WITH SOME SILTY GRAVEL
- INTERBEDDED SANDSTONE — APPROXIMATELY 90% MUDSTONE
- OCCASIONAL THIN INTERBEDS OF MUDSTONE
- INTERBEDDED MUDSTONE AND OCCASIONAL LENSES OF — APPROXIMATELY 90% SANDSTONE
- CONGLOMERATE — APPROXIMATELY 70% SANDSTONE
- SAND AND SANDSTONE — APPROXIMATELY 80% CONGLOMERATE

SYMBOLS

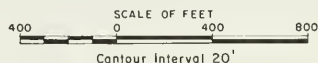
- BEDS
- DASHED WHERE INFERRED OR APPROXIMATELY LOCATED

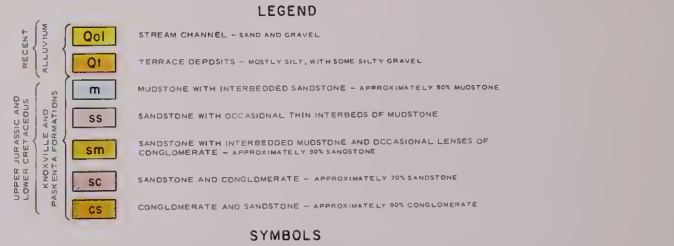
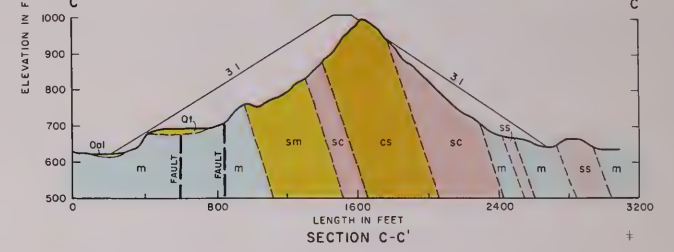
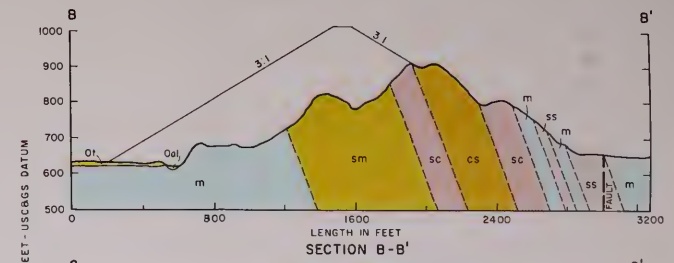
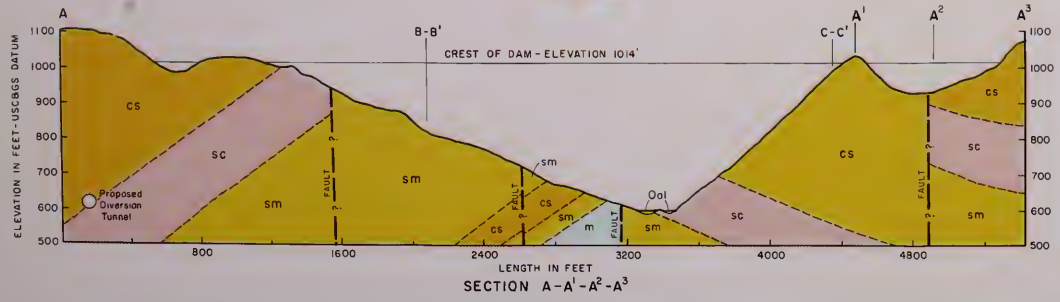
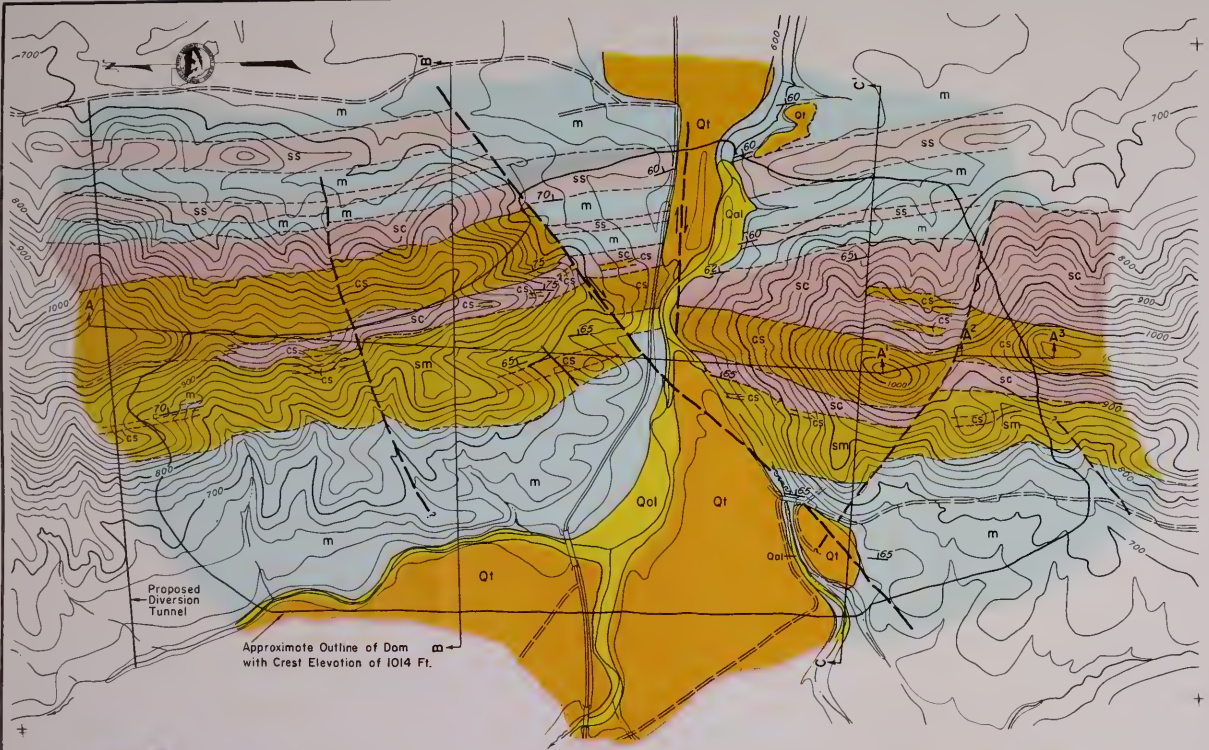
WHERE INFERRED OR APPROXIMATELY LOCATED

LINE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION

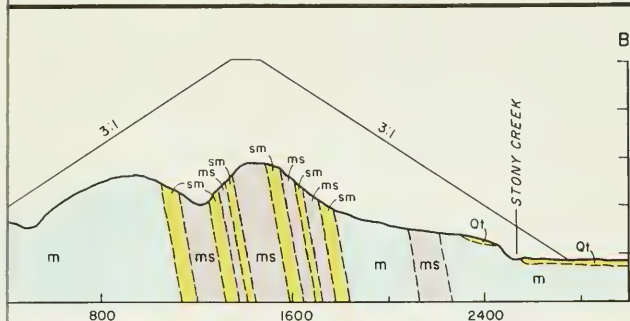
GEOLOGIC MAP AND SECTIONS NEWVILLE DAMSITE-N FK STONY CREEK



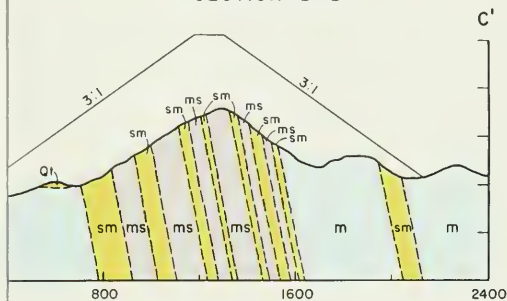


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTIONS
NEWVILLE DAMSITE-N FK STONY CREEK
SCALE OF FEET
0 400 800
Contour Interval 20'





SECTION B-B'



SECTION C-C'

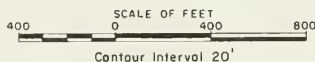
LEGEND

- STREAM CHANNEL DEPOSITS - SAND AND GRAVEL
- TERRACE DEPOSITS - CLAYEY GRAVELS
- MUDSTONE WITH INTERBEDDED SANDSTONE - APPROXIMATELY 90% MUDSTONE
- MUDSTONE WITH INTERBEDDED SANDSTONE - APPROXIMATELY 65% MUDSTONE
- MUDSTONE WITH INTERBEDDED MUDSTONE - APPROXIMATELY 85% SANDSTONE

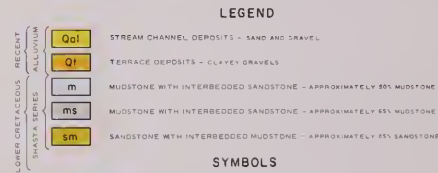
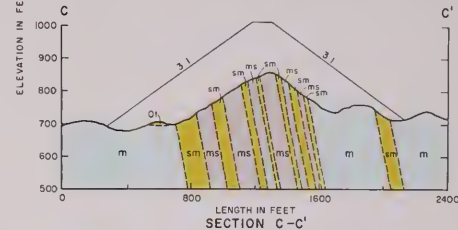
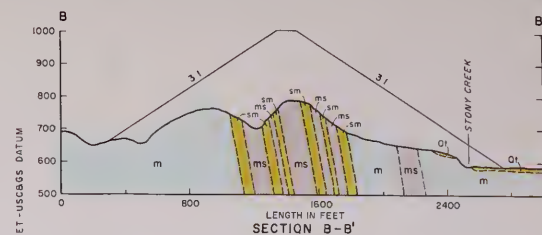
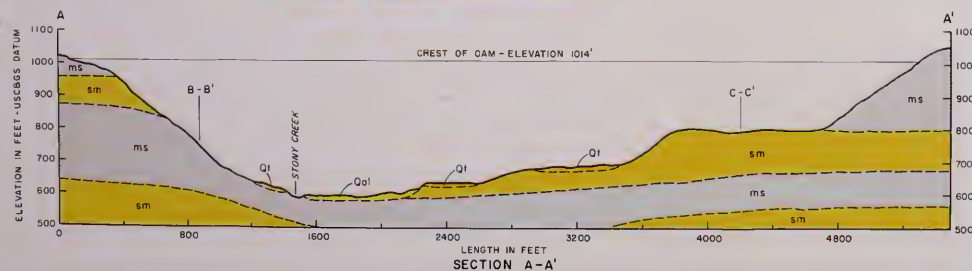
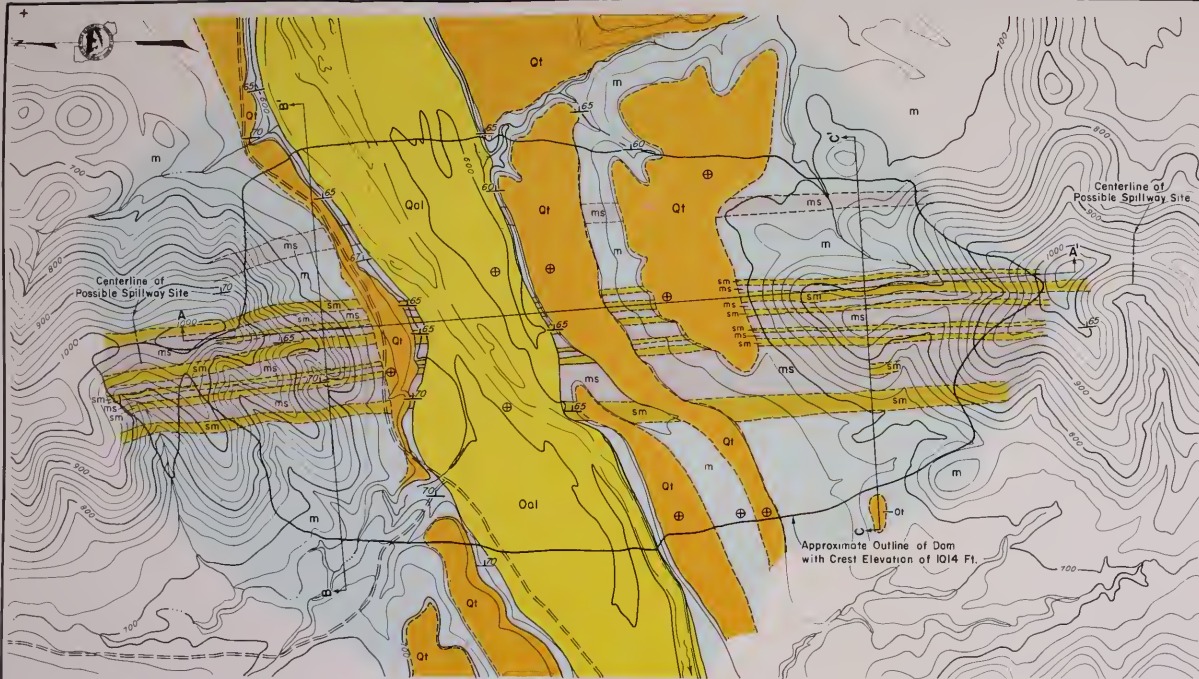
SYMBOLS

- GEOLOGIC CONTACT - DASHED WHERE INFERRED OR PROJECTED
- DIP AND STRIKE OF BEDS
- WATER HOLE
- GEOLOGIC SECTION LINE

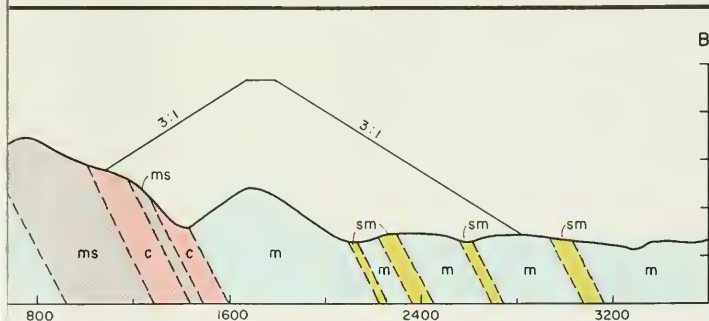
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTIONS
RANCHERIA DAMSITE-STONY CREEK



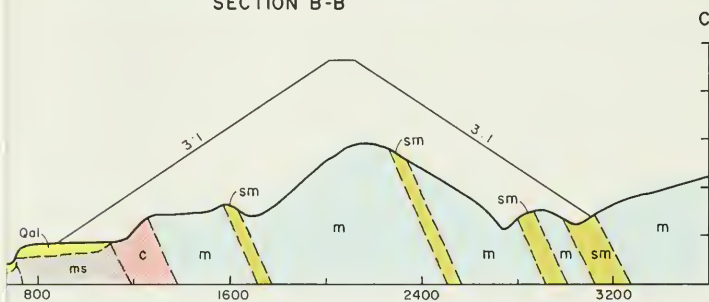
85878







SECTION B-B'



SECTION C-C'

LEGEND

ANNEL DEPOSITS - SAND AND GRAVELS

EPOSITS - CLAYEY GRAVELS WITH SDME SILTS AND FINE SANDS

WITH INTERBEDDED SANDSTONE - APPROXIMATELY 90% MUDSTONE

WITH INTERBEDDED SANDSTONE - APPROXIMATELY 65% MUDSTONE

WITH INTERBEDDED MUDSTONE - APPROXIMATELY 90% SANDSTONE

RATE - CONTAINS SOME BEDS AND LENSES OF SANDSTONE

SYMBOLS

ONTACT - DASHED WHERE INFERRED OR PROJECTED.

IKE OF BEDS

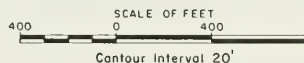
HOLE

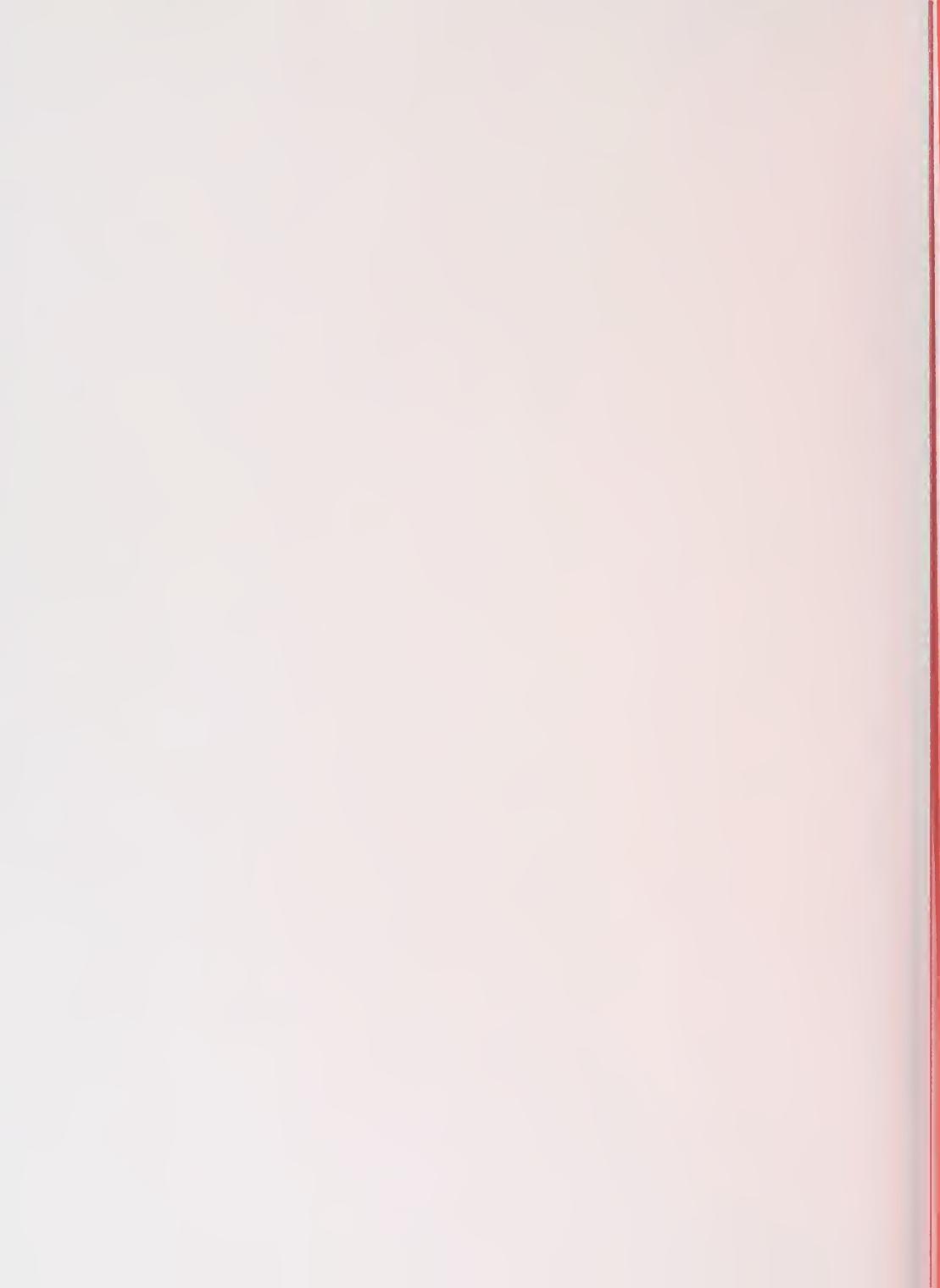
ECTION LINE

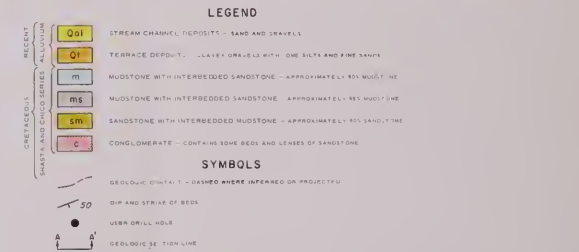
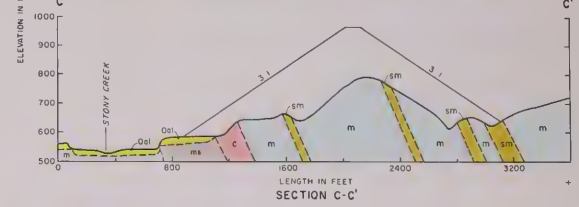
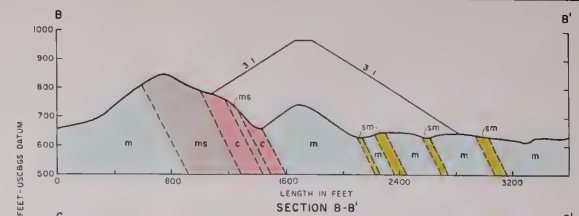
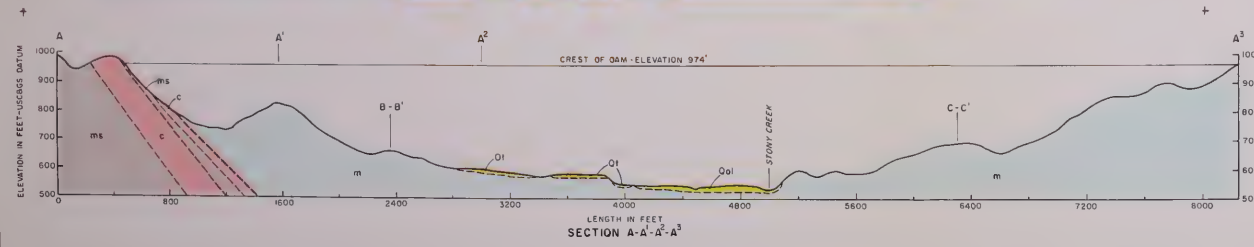
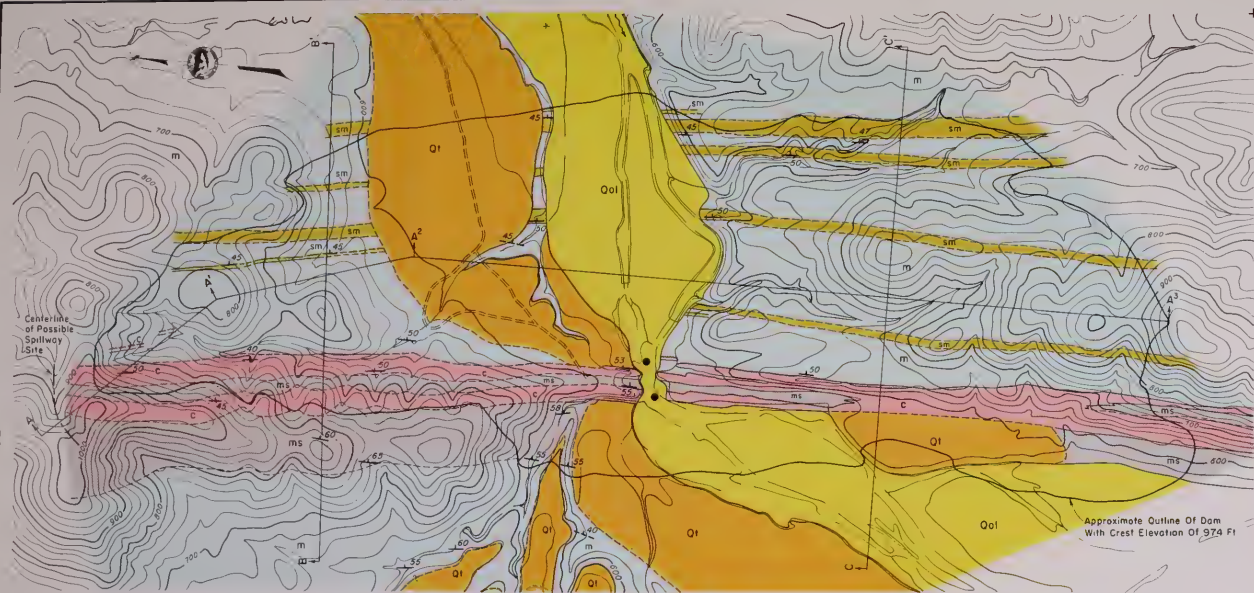
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTIONS MILLSITE DAMSITE-STONY CREEK







STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTIONS
MILLSITE DAMSITE-STONY CREEK
SCALE OF FEET
0 400 400
Contour Interval 20'



END

L, SAND AND SILT MIXTURES
 VEL, SAND AND CLAY MIXTURES
 AND CLAY MIXTURES
 OR CLAYEY FINE SANDS OR
 GHT PLASTICITY
 LOW TO MEDIUM PLASTICITY,
 SILTY CLAYS, LEAN CLAYS.
 GANIC SILTY CLAYS OF LOW

(SHELBY TUBE)

OWING ND, OF SACKS

DATE

Note: Classification is based on field data.
 Symbols are unified soil classification
 system.

DEPOSITS

CLAYEY GRAVELS

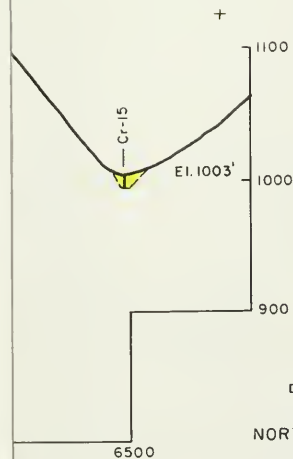
CLAY

IN SANDSTONE INTERBEDS

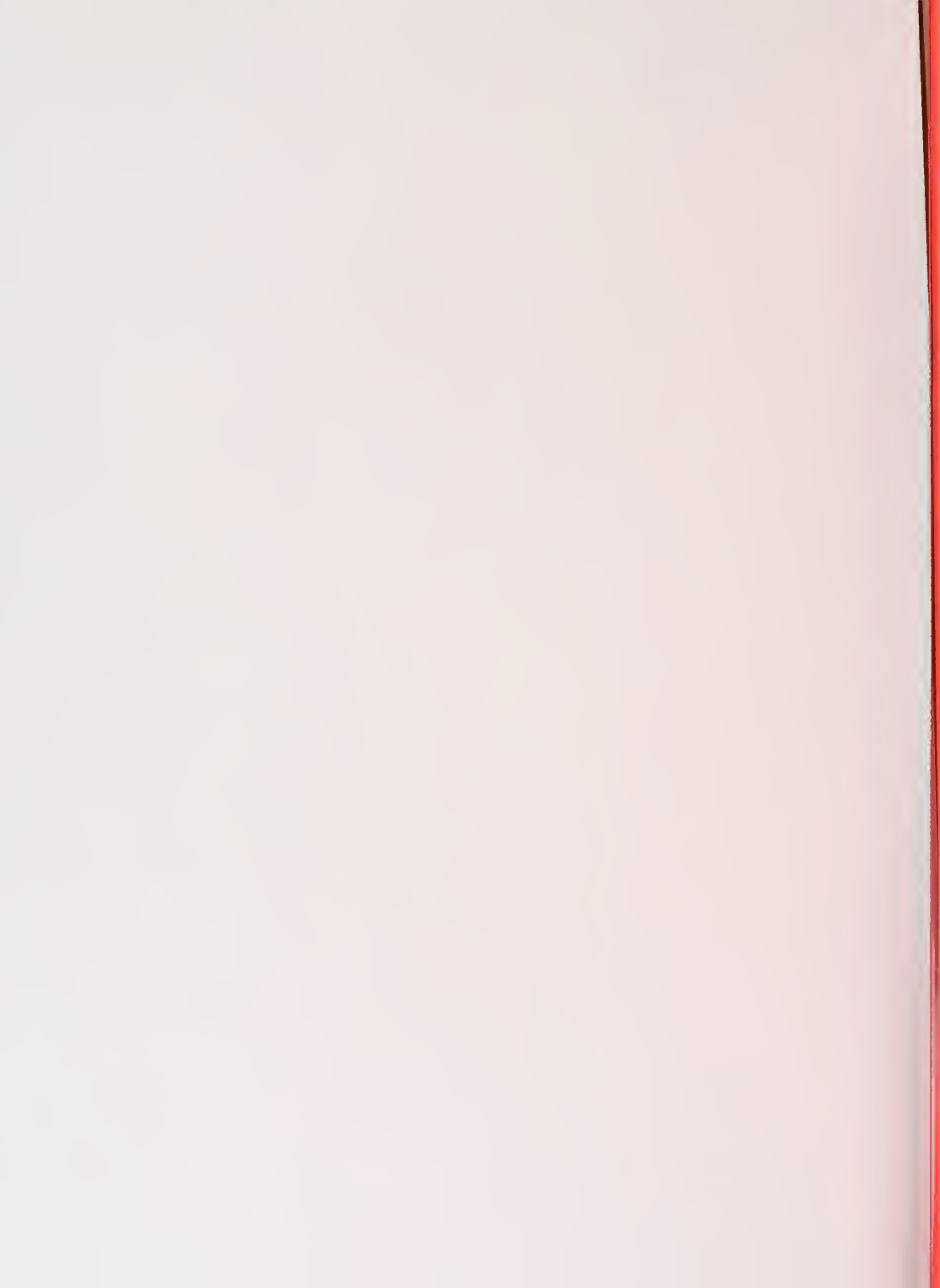
OSTONE

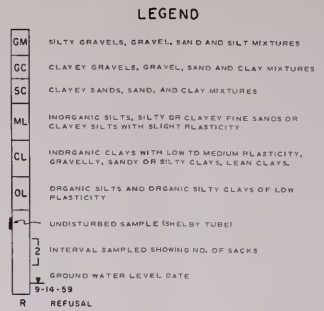
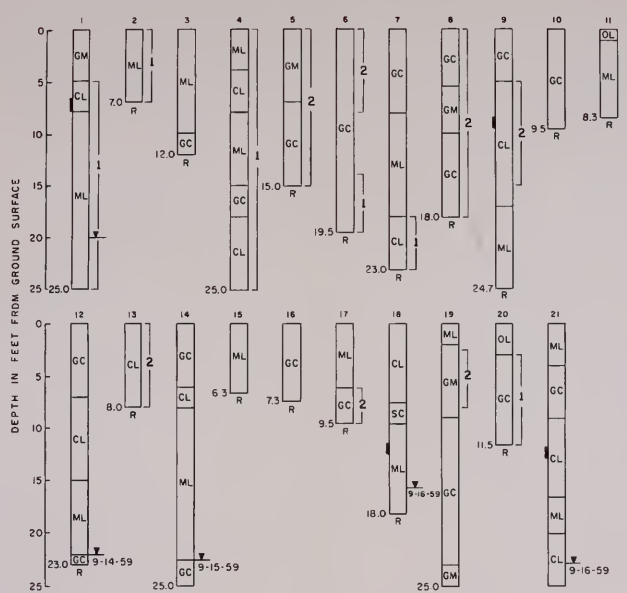
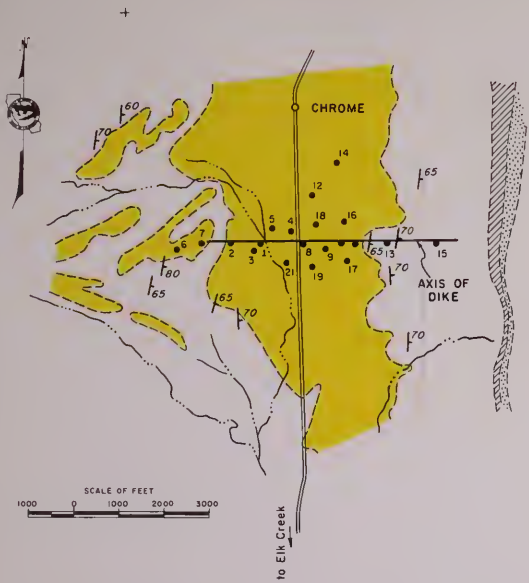
ODDING

Note: Geologic map-based on U.S. Dept.
 of Agriculture Aerial Photo

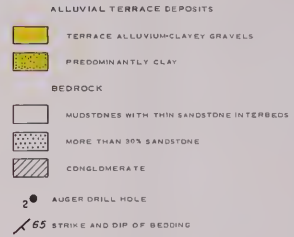


STATE OF CALIFORNIA
 THE RESOURCES AGENCY
 DEPARTMENT OF WATER RESOURCES
 NORTHERN BRANCH
 NORTH COASTAL AREA INVESTIGATION
 GEOLOGIC MAP, SECTION & LOGS
 CHROME DIKESITE
 GLENN RESERVOIR COMPLEX

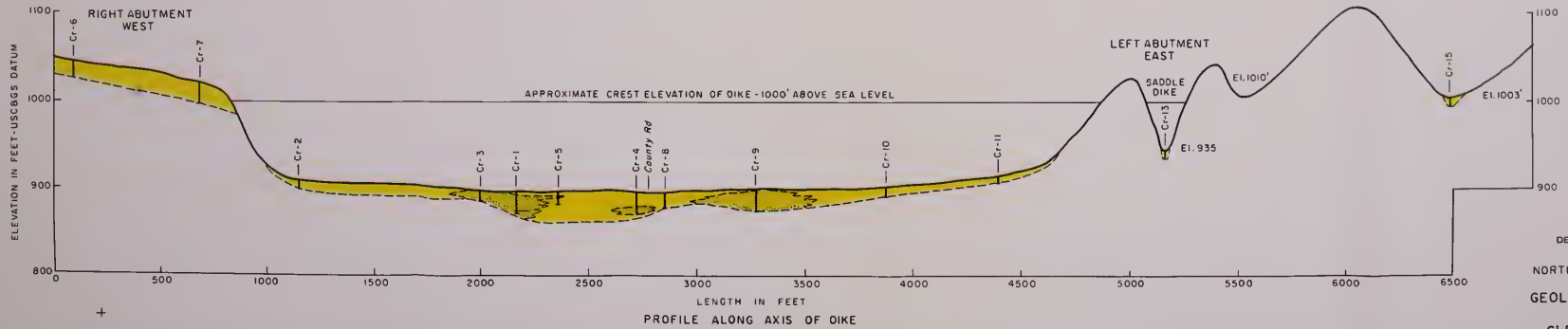




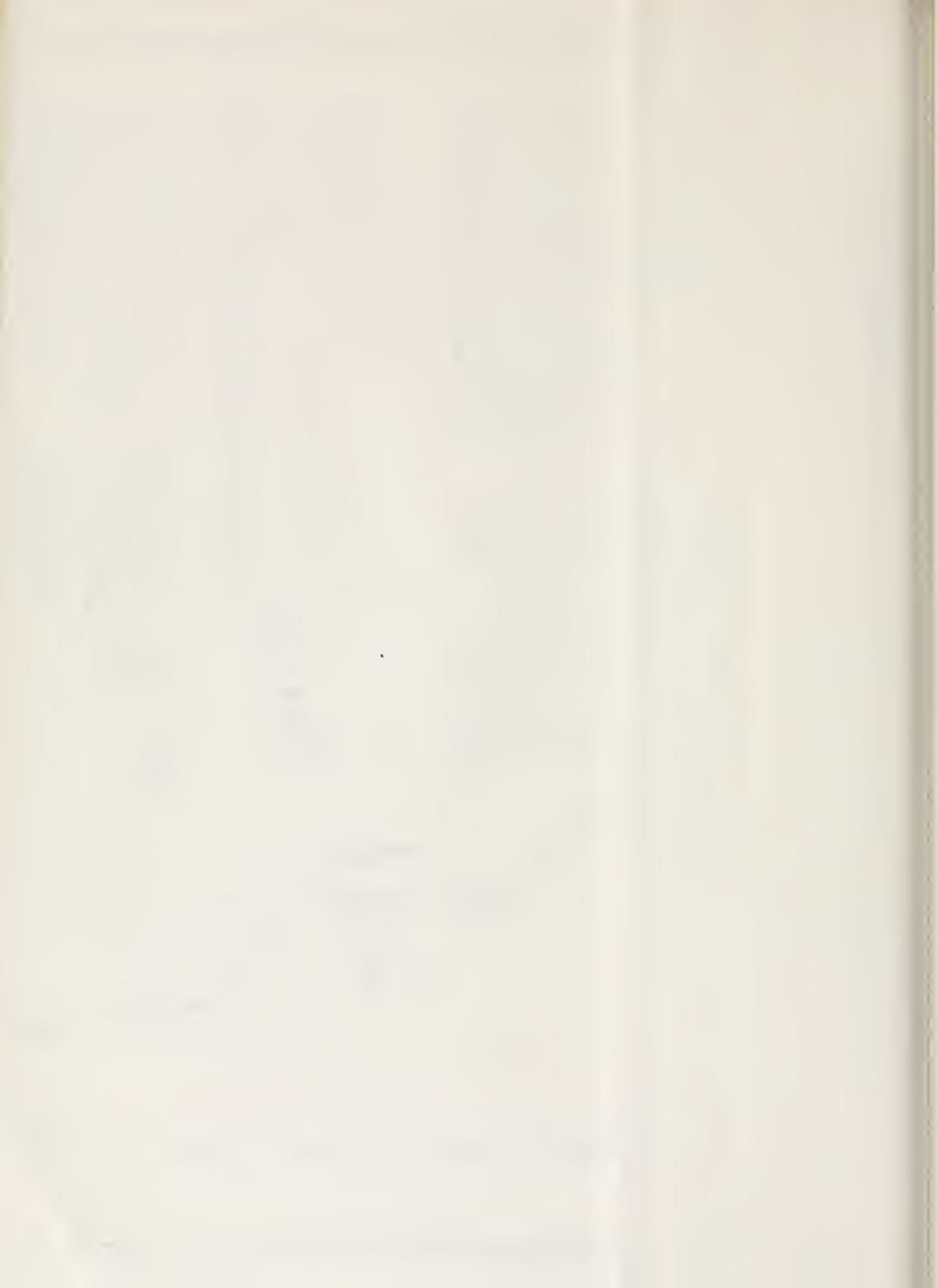
Note: Classification is based on field data. Symbols are unified soil classification system.








Note: Geologic map based on U.S. Dept. of Agriculture Aerial Photo



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP, SECTION 8 LOGS
CHROME DIKESITE
GLENN RESERVOIR COMPLEX

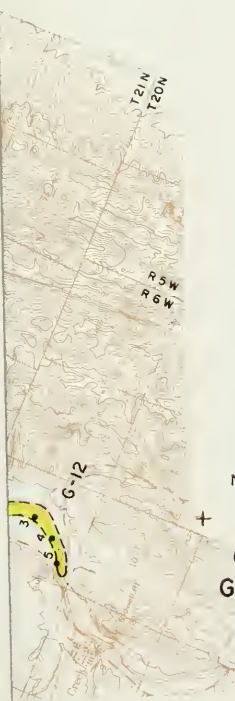


LEGEND

- G-1 to G-17  STREAM CHANNEL DEPOSITS - PERVIOUS
- T-1 to T-34  TERRACE & SLOPEWASH MAT'L-IMPERVIOUS.
- TF-1,2,3,4  TEHAMA FORMATION - IMPERVIOUS.
- OA-1,2,3, and OA-7,8  JURASSIC & CRETACEOUS CONGLOMERATE AND SANDSTONE-ROCKFILL & RIP RAP (cgl,ss).
- OA-4,5,6,  FRANCISCAN (?) FORMATION META-VOLCANIC OR BASIC IGNEOUS ROCKS-ROCKFILL & RIP RAP (bi,sp).
- AUGER HOLES, WILLIAMS RIG. MAX. DEPTH = 25 FT.
- DIAMOND CORE HOLES - QUARRY AREAS.

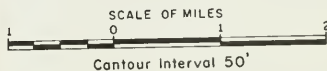
HOLE LOCATIONS

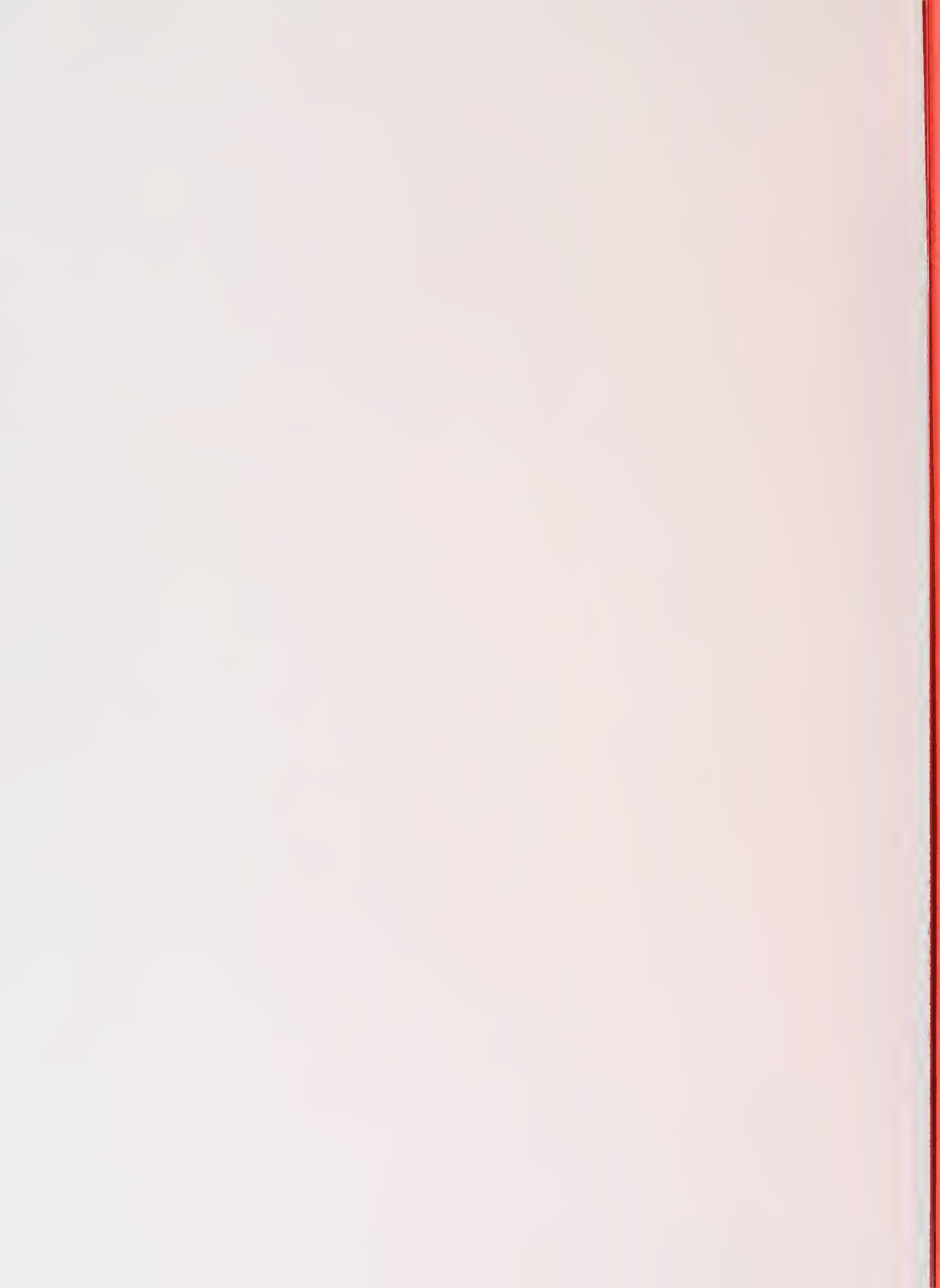
BORROW AREA	AUGER HOLES
TF-1, TF-2.	MS-101 to MS-145.
TF-3, TF-4	N-1 to N-29.
T-1 to T-10	R-3 to R-39.
T-11 to T-19	MS-26 to MS-64.
T-20A to T-23	CR-1 to CR-21.
T-24 to T-32	N-31 to N-35.
T-33, T-34	NF-1 to NF-3. N-19, N-20, N-30.
G-1 to G-3	MS-70 to MS-97.
G-4 to G-6	R-1, R-2; MS-1, MS-2; CP-1; MS-65 to MS-69; MS-98 to MS-100.
G-7 to G-12	MS-3 to MS-25; MS-38 to MS-42, CP-2, CP-3.
G-13	N1A, N1B, N1C.

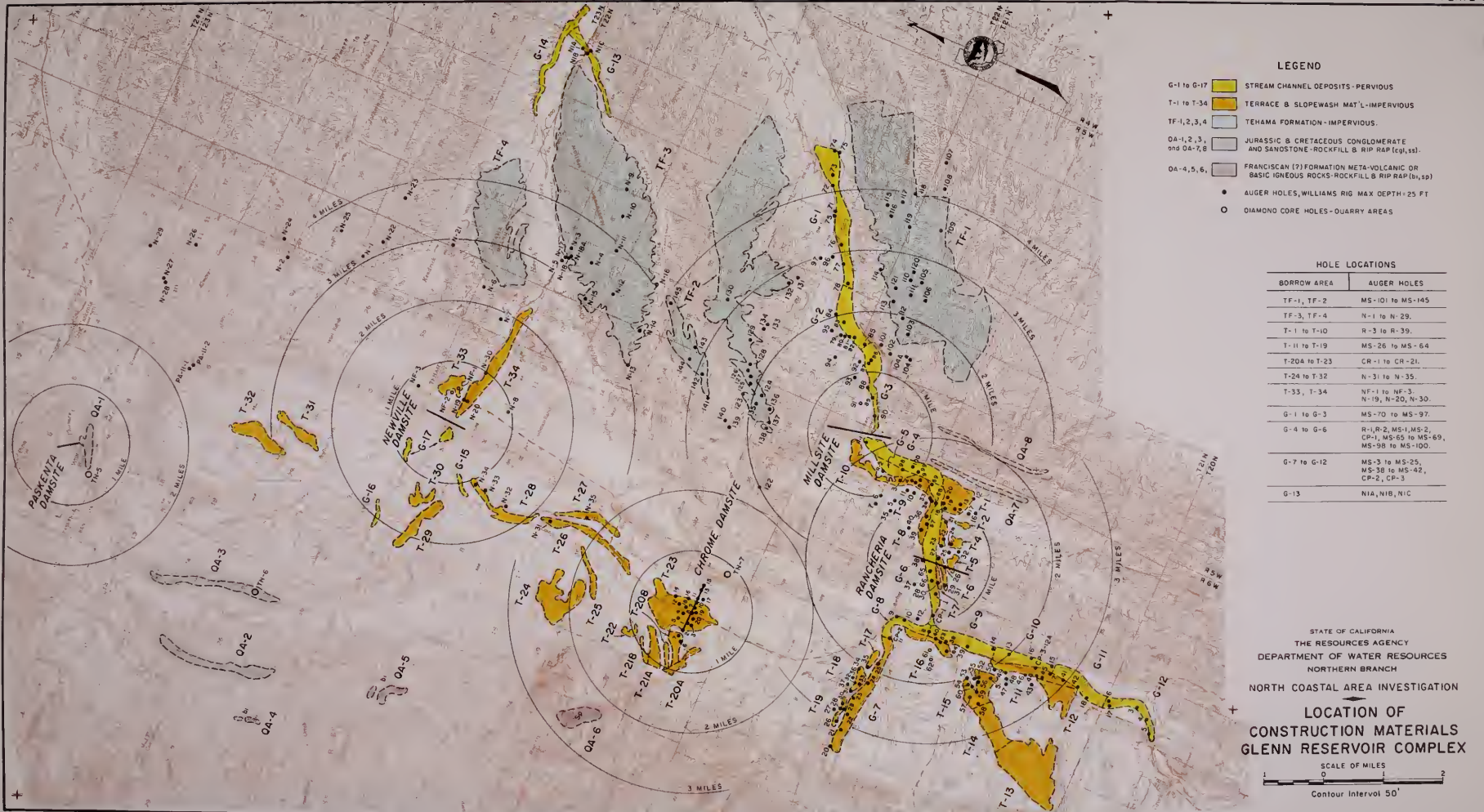


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS GLENN RESERVOIR COMPLEX







LEGEND

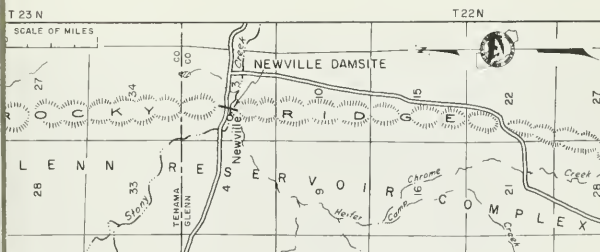
- MUDSTONE**
DARK GRAY, SOFT, THINLY BEDDED, OFTEN INTERBEDDED WITH THIN BEDS OF FINE-GRAINED SANDSTONE. ESTIMATED AVERAGE UNCONFINED COMPRESSIVE STRENGTH - 2,000 PSI, SLAKES IN AIR.
- SANDSTONE**
MEDIUM GRAY, FINE-GRAINED, SOFT TO MODERATELY HARD, THINLY BEDDED, ESTIMATED AVERAGE UNCONFINED COMPRESSIVE STRENGTH - 6,000 PSI.
- SANDSTONE AND CONGLOMERATE**
GRAY WITH VARI-COLORED PEBBLES; FINE TO COARSE-GRAINED SANDSTONE; PEBBLE TO LARGE COBBLE CONGLOMERATE; MODERATELY HARD; USUALLY MASSIVE. TESTED AVERAGE UNCONFINED COMPRESSIVE STRENGTH OF SANDSTONE - 11,000 PSI. TESTED AVERAGE UNCONFINED COMPRESSIVE STRENGTH OF CONGLOMERATE - 9,700 PSI. CONGLOMERATE MAKES ABOUT 25% OF UNIT.
- CONGLOMERATE WITH SANDSTONE**
GRAY WITH VARI-COLORED PEBBLES; FINE TO COARSE-GRAINED SANDSTONE, PEBBLE TO LARGE COBBLE CONGLOMERATE; HARD, MASSIVE. STRENGTHS SAME AS IN ABOVE UNIT. SANDSTONE MAKES ABOUT 30% OF UNIT.

SYMBOLS

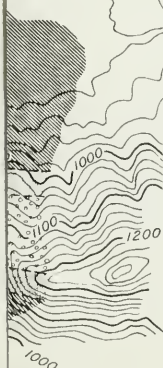
- DIP AND STRIKE OF BEDDING
- GEOLOGIC CONTACT - DASHED WHERE APPROXIMATELY LOCATED
- FAULT - DASHED WHERE APPROXIMATELY LOCATED
- SPRING
- SEEP
- VERTICAL DIAMOND CORE HOLE
- INCLINED DIAMOND CORE HOLE
- LINE OF GEOLOGIC CROSS SECTION
- AXIS OF DAM OR SADDLE DAM

NOTE: THIS MAPPING WAS ACCOMPLISHED IN MAY 1960 BY DEPARTMENT OF WATER RESOURCES PERSONNEL

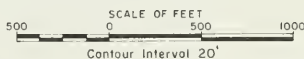
NOTE: GEOLOGIC SECTIONS APPEAR ON PLATE 17

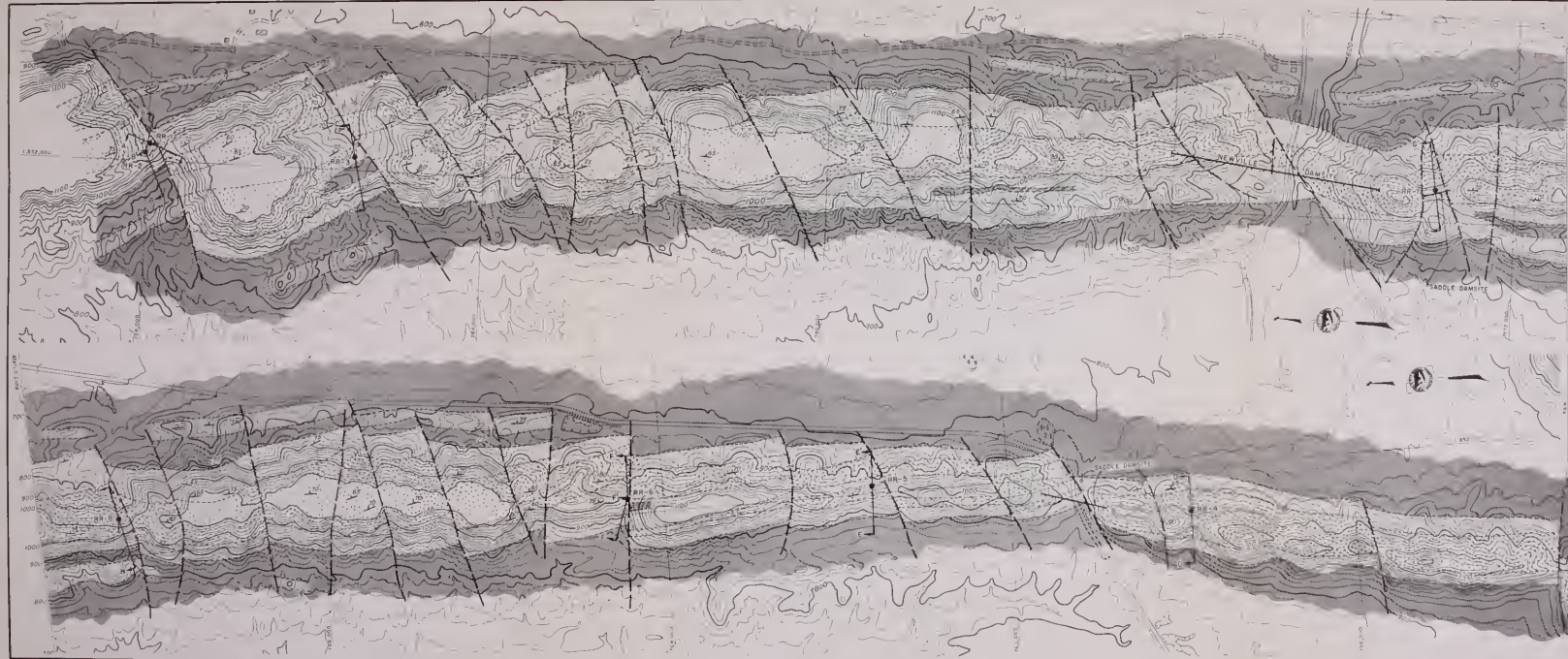


LOCATION MAP



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP
ROCKY RIDGE - EAST RIM OF
NEWVILLE RESERVOIR





LEGEND

UNIT

AT TOWN RECORD - INTEREST 1
AT TOWN RECORD - INTEREST 2
AT TOWN RECORD - INTEREST 3
AT TOWN RECORD - INTEREST 4
AT TOWN RECORD - INTEREST 5
AT TOWN RECORD - INTEREST 6
AT TOWN RECORD - INTEREST 7
AT TOWN RECORD - INTEREST 8
AT TOWN RECORD - INTEREST 9
AT TOWN RECORD - INTEREST 10

SANDSTONE

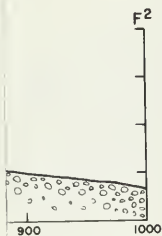
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS
SANDSTONE AND CALCAREOUS

SYMBOLS

OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN
OF A LINE OF 100 FT. IN

LOCATION MAP

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP
ROCKY RIDGE - EAST RIM OF
NEWVILLE RESERVOIR
SCALE OF FEET
Contour Interval 20



LEGEND

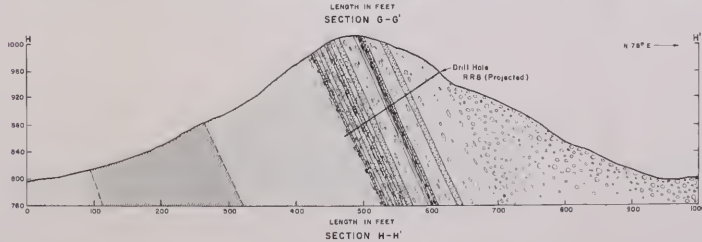
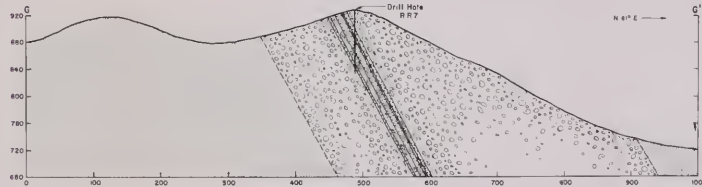
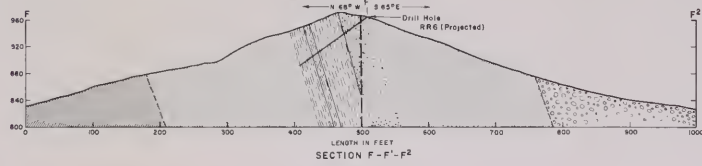
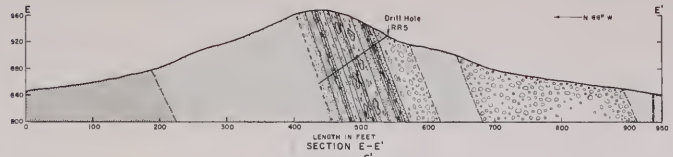
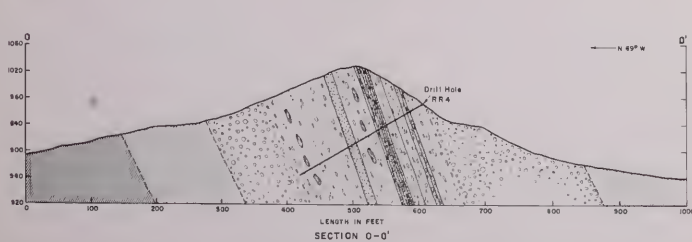
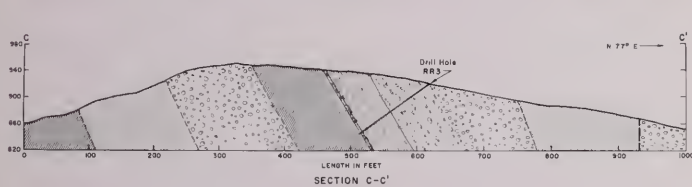
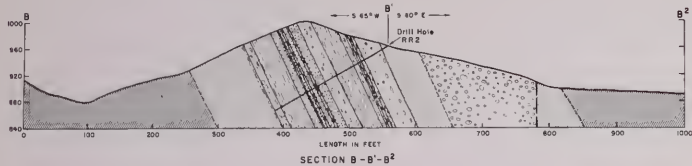
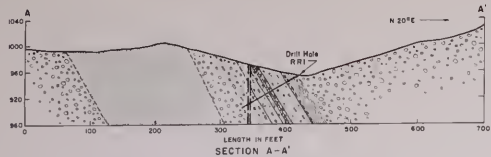
KNOXVILLE FORMATION
UPPER JURASSIC & LOWER CRETACEOUS

- MUDDSTONE, INVESTIGATED WITH DRILL HOLE.
- MUDDSTONE WITH OCCASIONAL SANDSTONE BECS. NOT MAPPED IN DETAIL.
- SANDSTONE, INVESTIGATED WITH DRILL HOLE.
- SANDSTONE WITH INTERBEDS OF CONGLOMERATE. NOT MAPPED IN DETAIL.
- CONGLOMERATE, INVESTIGATED WITH DRILL HOLE.
- CONGLOMERATE WITH INTERBEDS OF SANDSTONE. NOT MAPPED IN DETAIL.

- GEOLOGIC CONTACT - DASHED WHERE APPROXIMATELY LOCATED.
- FAULT - DASHED WHERE APPROXIMATELY LOCATED.

NOTE: LOCATION OF SECTIONS APPEAR ON PLATE 16

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC SECTIONS
ROCKY RIDGE - EAST RIM OF
NEWVILLE RESERVOIR

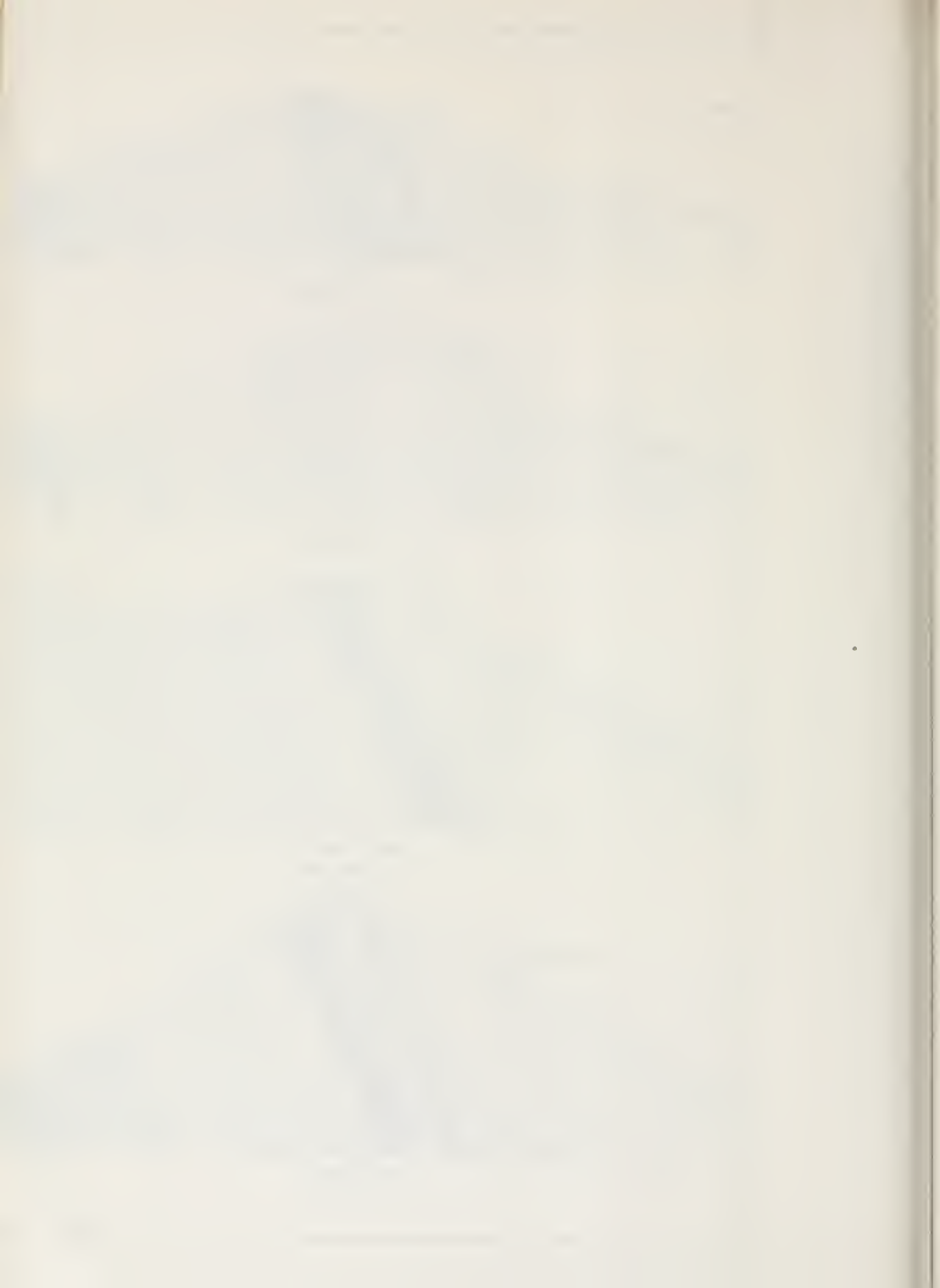


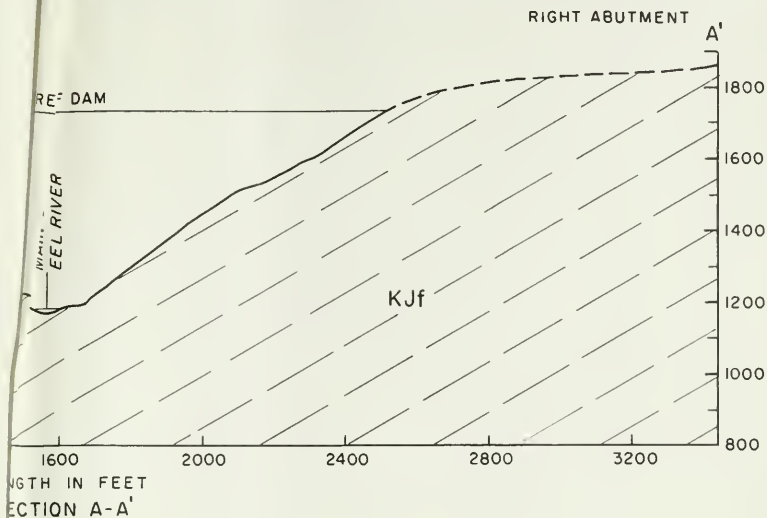
LEGEND

- MUDSTONE - INVESTIGATED WITH DRILL HOLE
 MUDSTONE WITH OCCASIONAL SANDSTONE BEDS NOT MAPPED IN DETAIL
 SANDSTONE - INVESTIGATED WITH DRILL HOLE
 SANDSTONE WITH INTERBEDS OF CONGLOMERATE NOT MAPPED IN DETAIL
 CONGLOMERATE - INVESTIGATED WITH DRILL HOLE
 CONGLOMERATE WITH INTERBEDS OF SANDSTONE NOT MAPPED IN DETAIL
- GEOLOGIC CONTACT - DASHED WHERE APPROXIMATELY LOCATED
 FAULT - DASHED WHERE APPROXIMATELY LOCATED

NOTE LOCATION OF SECTIONS APPEAR ON PLATE 16

STATE OF CALIFORNIA
 THE RESOURCES AGENCY
 DEPARTMENT OF WATER RESOURCES
 NORTHERN BRANCH
 NORTH COASTAL AREA INVESTIGATION
 GEOLOGIC SECTIONS
 ROCKY RIDGE - EAST RIM OF
 NEWVILLE RESERVOIR





LEGEND

COVERED BY A NEARLY CONTINUOUS MANTLE OF SLOPEWASH, RESIDUAL AVERAGE DEPTH OF 15 TO 20 FEET.

THE ACTIVE CHANNEL ARE HIGHLY IRREGULAR AND HAVE NOT BEEN STUDIED SINCE STUDY.

THE APPROXIMATE RATIO OF SANDSTONE TO SHALE IN THE DAM FOUND OUTCROPS ARE GOOD IN THE CHANNEL SECTION AND ARE SPOTTY

SYMBOLS

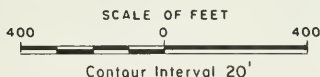
APPROXIMATELY LOCATED

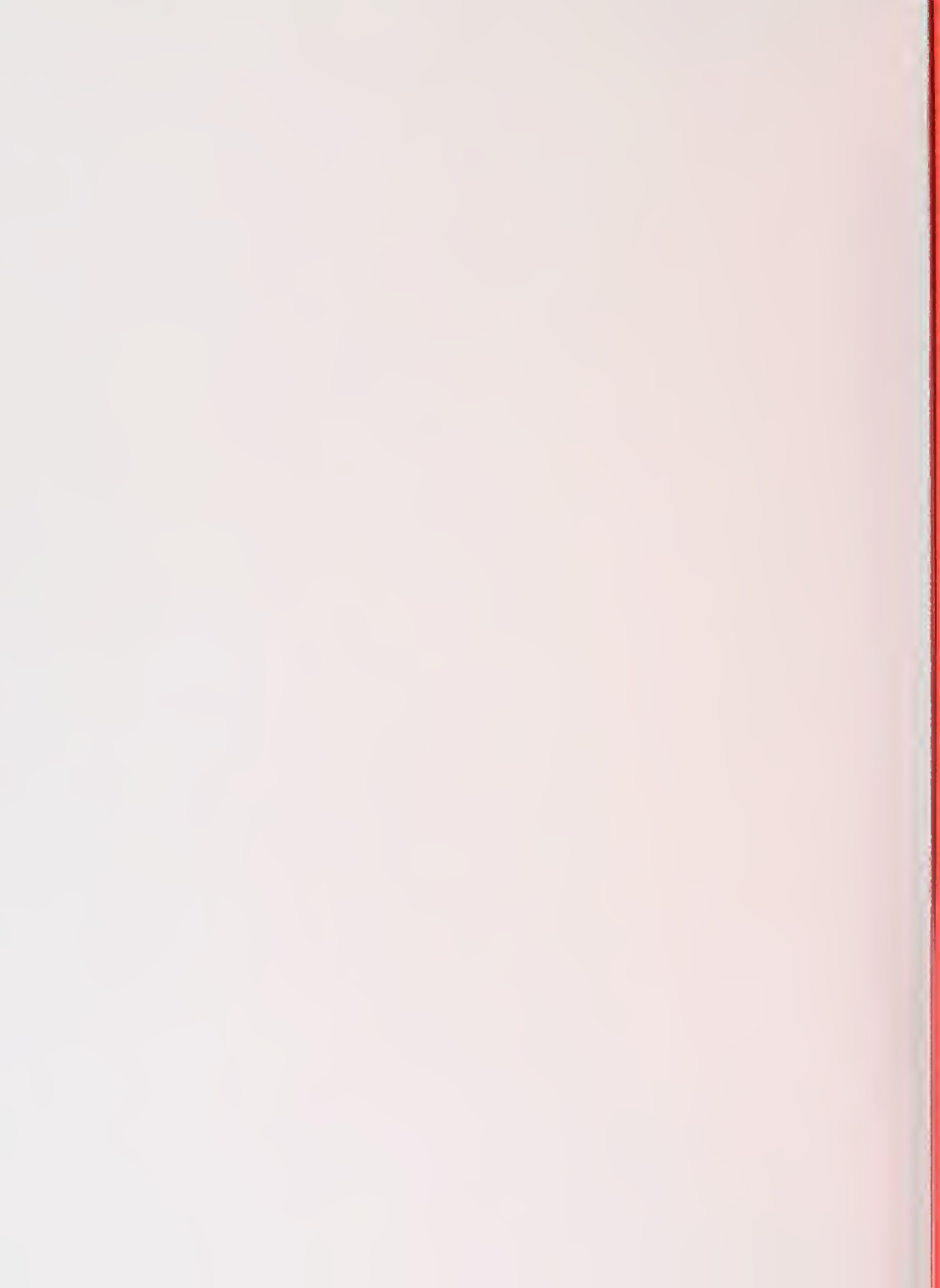
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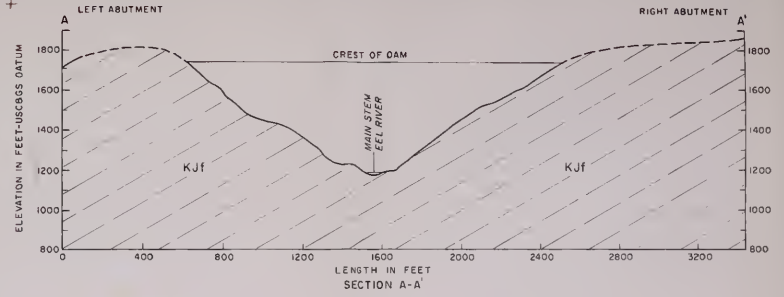
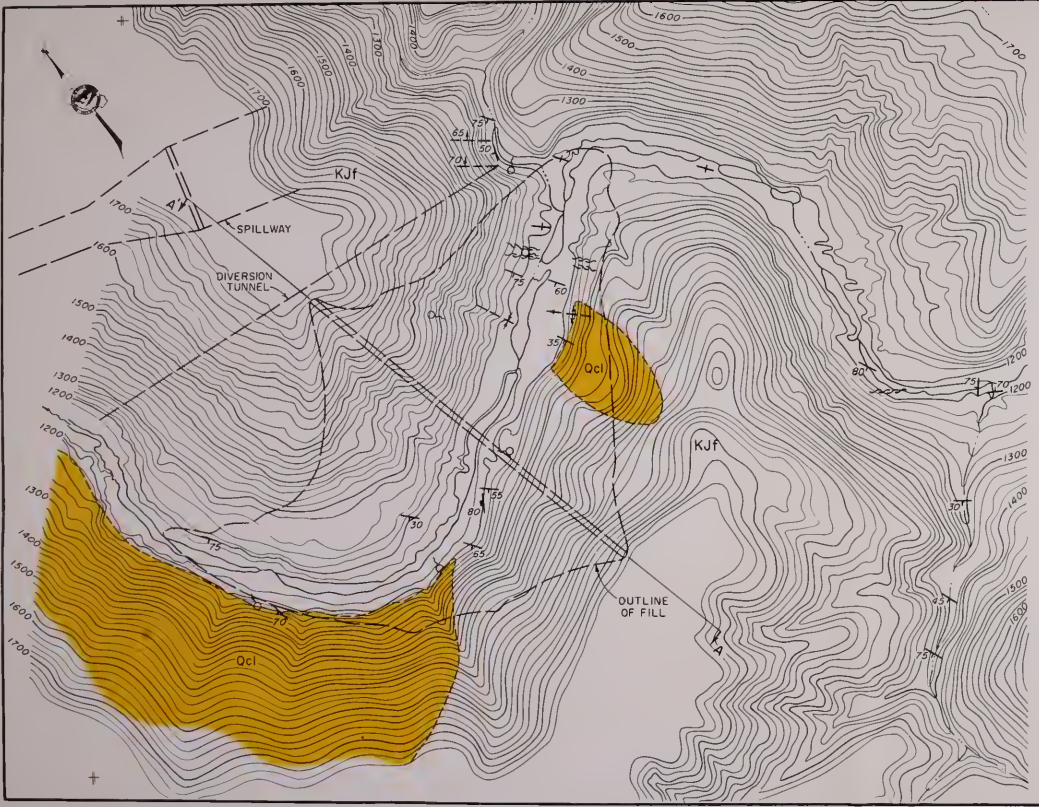
LOWAY AND DIVER-

BASED ON AN

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTION
ENGLISH RIDGE DAMSITE - EEL RIVER







OVERBURDEN

QUATERNARY **Qcl** DEEP COLLUVIUM—AREAS OUTLINED ARE COVERED BY A NEARLY CONTINUOUS MANTLE OF SLOPEWASH, RESIDUAL SOIL AND LANDSLIDE DEBRIS TO AN AVERAGE DEPTH OF 15 TO 20 FEET.

NOTE: THE STREAM ALLUVIUM DEPOSITS IN THE ACTIVE CHANNEL ARE HIGHLY IRREGULAR AND HAVE NOT BEEN DIFFERENTIATED DURING THE RECONNAISSANCE STUDY.

FRANCISCAN FORMATION

KJf SANDSTONE WITH SHALE INTERBEDS—THE APPROXIMATE RATIO OF SANDSTONE TO SHALE IN THE DAM FOUNDATIONS WAS ESTIMATED AT 65% TO 35%. OUTCROPS ARE GOOD IN THE CHANNEL SECTION AND ARE SPOTTY ON THE ABUTMENTS.

- SYMBOLS**
- GEOLOGIC CONTACT
 - NOTE: OVERBURDEN CONTACTS ARE ONLY APPROXIMATELY LOCATED
 - / 70 STRIKE AND DIP OF STRATA
 - x STRIKE OF VERTICAL STRATA
 - / 80 STRIKE AND DIP OF JOINTS
 - SHEAR ZONE
 - |- MINOR FAULT SHOWING DIRECTION OF DIP
 - |- MINOR FOLD SHOWING DIRECTION OF AXIAL PLUNGE
 - + SPRING OR SEEP
 - A-A' GEOLOGIC SECTION LINE

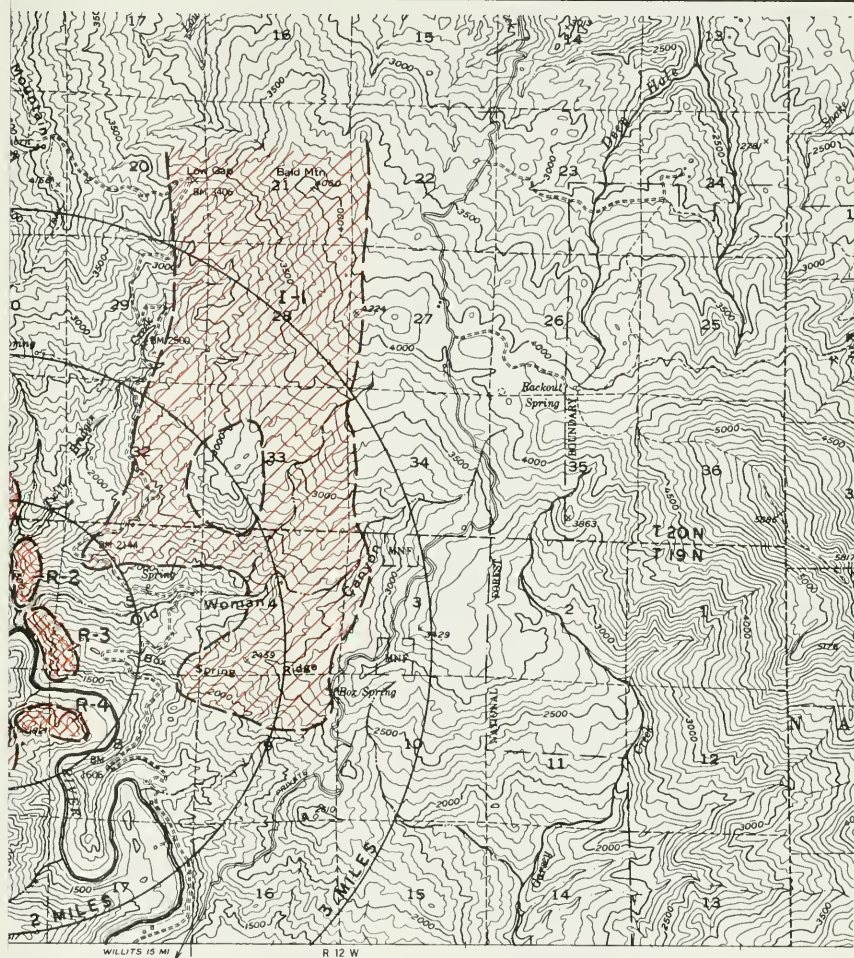
NOTE: THE OUTLINES OF THE DAM EMBANKMENT, SPILLWAY AND DIVERSION TUNNEL ARE PARTIALLY DIAGRAMMATIC.

NOTE: THE READING PROJECTED ON THE SECTION IS BASED ON AN AVERAGE STRIKE OF S45W AND A 50° DIP.

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SCALE OF FEET
400 0 400
Contour Interval 20'





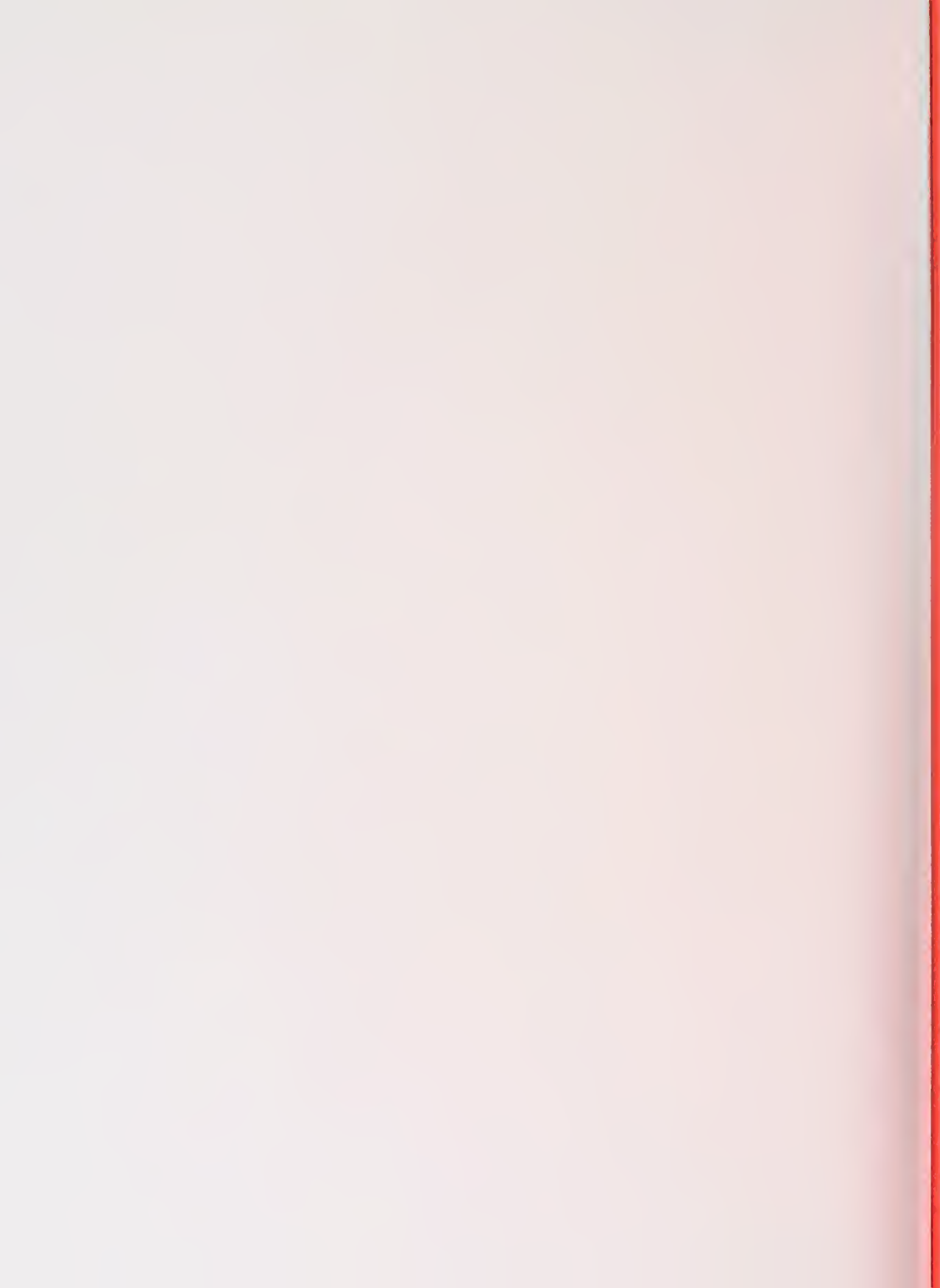
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THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
ENGLISH RIDGE DAMSITE-EEL RIVER

SCALE OF MILES







LEGEND



IMPERVIOUS-SOIL, SLOPEWASH AND LANDSLIDE DEBRIS
DEVELOPED ON SHEARED FRANCISCAN SHALE. PHYSICAL
PROPERTIES AND THE DEPTH OF THIS MATERIAL ARE EX-
PECTED TO VARY CONSIDERABLY.



ROCKFILL-FRANCISCAN SANDSTONE; BEDDED GRAYWACKE
WITH LESS THAN 15% OF SHALE.

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ENGLISH RIDGE DAMSITE-EEL RIVER

SCALE OF MILES





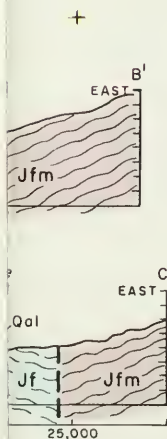
LEGEND

Qal	STREAM ALLUVIUM - SAND AND GRAVEL
Qls	LANDSLIDES
Ks	SHASTA SERIES - UNDIFFERENTIATED SEQUENCE OF SANDSTONE, SHALE, AND MINOR CONGLOMERATE
FRANCISCAN GROUP	
Jf	FRANCISCAN GROUP UNDIFFERENTIATED - GRAYWACKE SANDSTONE, SHALE, CONGLOMERATE AND LENSES OF GREENSTONE, CHERT, SERPENTINE, AND GLAUCOPHANE SCHIST
Jfm	FRANCISCAN GROUP - SLIGHTLY METAMORPHOSED LITHOLOGIC EQUIVALENTS OF Jf.
Jfv	FRANCISCAN VOLCANIC ROCK - ALTERED BASIC VOLCANIC FLOWS
Jsp	SERPENTINE - INTENSELY SHEARED AND ALTERED ULTRABASIC INTRUSIVE ROCK

SYMBOLS

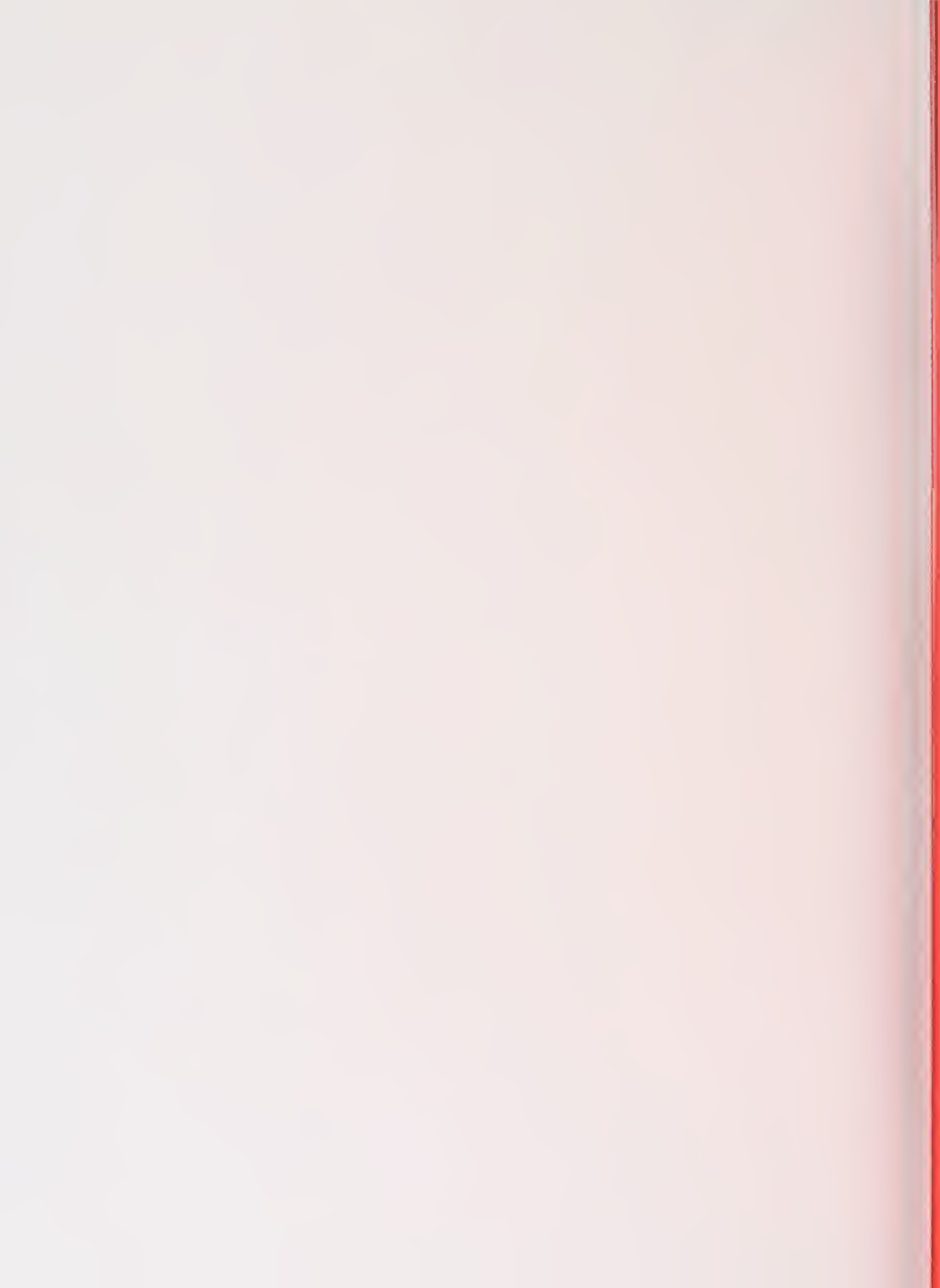
	STRIKE AND DIP OF BEDS		ALLUVIAL BOUNDARY
	STRIKE OF VERTICAL BEDS		FAULT-SHOWING RELATIVE MOVEMENT
	HORIZONTAL BEDS		FAULT-CONCEALED
	SPRING AND SEEPS		WEAK ZONE-SHEARED AND FRACTURED ROCK
	GEOLOGIC CONTACT-DASHED WHERE INDEFINITE		GEOLOGIC SECTION LINE

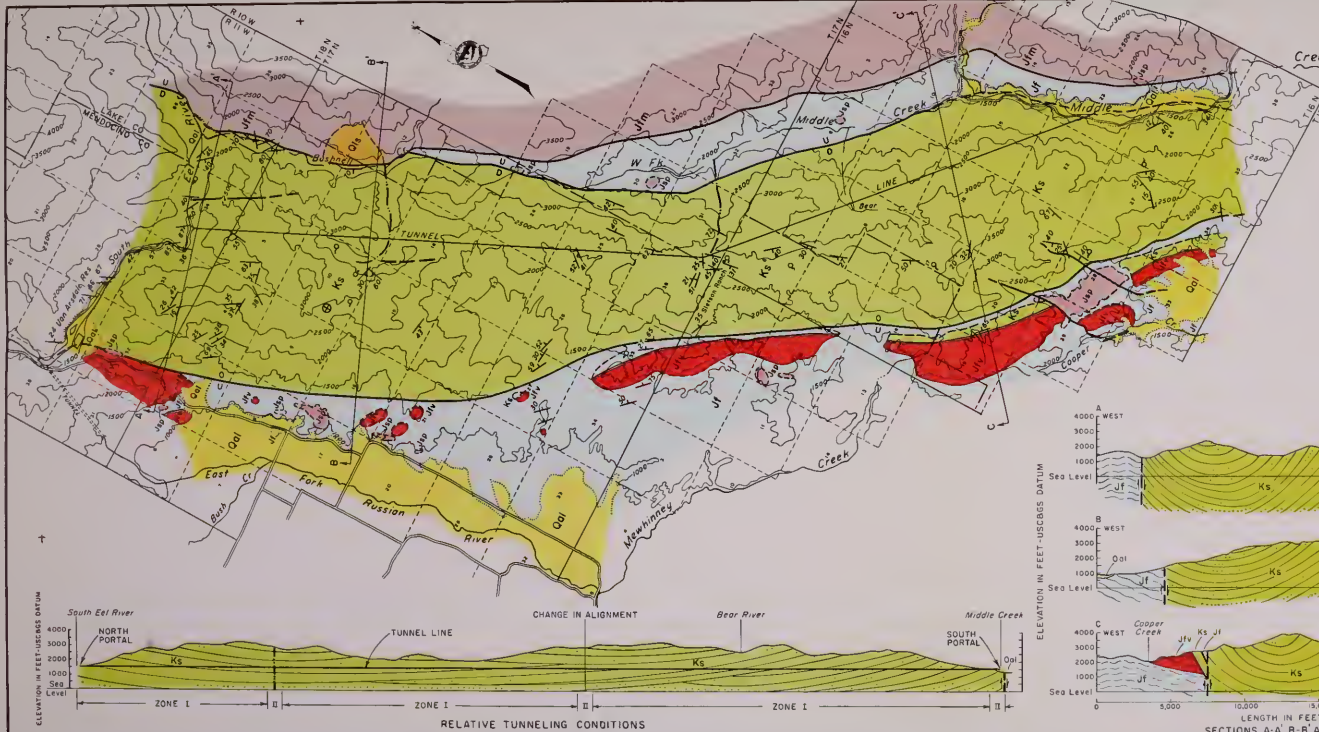
NOTE: REFER TO TEXT FOR A DETAILED DESCRIPTION OF RELATIVE TUNNELING CONDITIONS ZONES



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GARRETT TUNNEL







LEGEND

QUATERNARY

- Qol STREAM ALLUVIUM - SAND AND GRAVEL
- Qls LANDSLIDES
- Ks SHASTA SERIES - UNDIFFERENTIATED SEQUENCE OF SANDSTONE, SHALE, AND MUD CONGLOMERATE

LOWER CRETACEOUS

FRANCISCAN GROUP

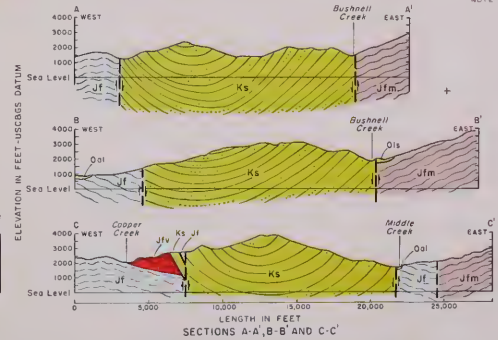
- Jf FRANCISCAN GROUP UNDIFFERENTIATED - GRAYWACKE SANDSTONE, SHALE, CONGLOMERATE AND LENSES OF GREENSTONE, CHERT, SERPENTINE, AND GLAUCOPHANE SCHIST
- Jfm FRANCISCAN GROUP - SLIGHTLY METAMORPHOSED LITHOLOGIC EQUIVALENTS OF Jf
- Jv FRANCISCAN VOLCANIC ROCK - ALTERED BASIC VOLCANIC FLOWS
- Jsp SERPENTINE - INTENSELY SHEARED AND ALTERED ULTRABASIC INTRUSIVE ROCK

UPPER JURASSIC TO LOWER CRETACEOUS

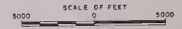
SYMBOLS

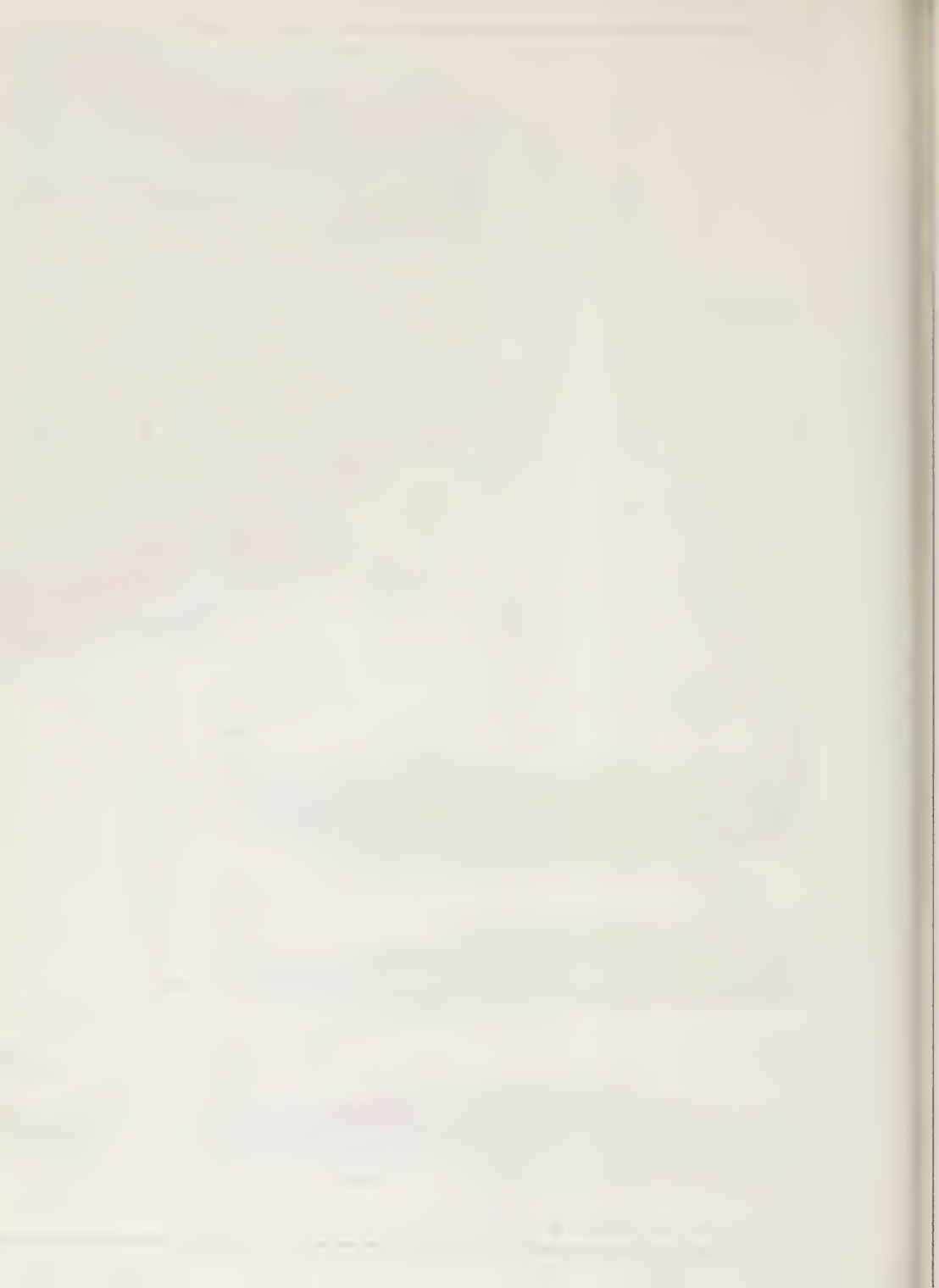
- 30 STRIKE AND DIP OF BEDS
- ⊕ STRIKE OF VERTICAL BEDS
- ⊗ HORIZONTAL BEDS
- ⊙ SPRING AND SEEPS
- GEOLGIC CONTACT-DASHED WHERE INDEFINITE
- ALLUVIAL BOUNDARY
- U FAULT-SHOWING RELATIVE MOVEMENT
- ⊕ FAULT-CONCEALED
- WEAK ZONE-SHEARED AND FRACTURED ROCK
- A A' GEOLGIC SECTION LINE

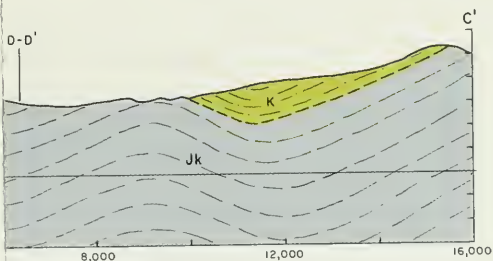
NOTE REFER TO TEXT FOR A DETAILED DESCRIPTION OF RELATIVE TUNNELING CONDITIONS ZONES



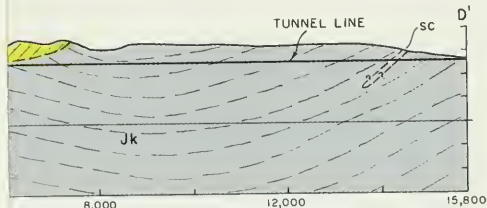
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GARRETT TUNNEL







SECTION C-C'



SECTION D-D'

LEGEND

ES (SERPENTINE OR LAVA USUALLY INVOLVED).

, CLAY, SAND, GRAVEL.

ASALT
TO LIGHT GRAY, PORPHYRITIC OLIVINE BASALT. PHENOCRYSTS
VINE AND PYROXENE. QUARTZ INCLUSIONS ARE COMMON.

RMATION
RAY SILT INTERBEDDED WITH GRAVEL AND SAND. TUFFS, TUFFACEOUS
PEBBLY LIMESTONE AND DIATOMITE OCCUR NEAR THE TOP OF THE SECTION.

4BONATE ROCK
MINERALS, FREQUENTLY OPAL, ASSOCIATED WITH CARBONATES OF THE
E GROUP. MAY HAVE A VEINED OR SCHISTOSE STRUCTURE. IT IS COMMONLY
N ELONGATED MASSES IN FAULT ZONES AND NEAR SERPENTINE.

RMATION
CONGLOMERATIC SANDSTONE. THE CONGLOMERATE OCCURS AS BEDS, LENSES
NGERS OF GENERALLY UNSORTED GRAVELS, PEBBLES OR COBBLES. QUARTZ,
AND VOLCANIC COBBLES PREDOMINATE.

FORMATION
NO CLAYEY SHALE, CONGLOMERATE AND WHITE AND YELLOW SANDSTONE. THE
MERATE CONTAINS POORLY SORTED PEBBLES OF CHERT, QUARTZ, AND IGNEOUS

US ROCKS (UNDIFFERENTIATED)
ONE AND SHALE IN APPROXIMATELY EQUAL PROPORTIONS. THE SANDSTONE IS
E, YELLOWISH BROWN, AND FINE TO MEDIUM GRAINED. IT IS POORLY SORTED AND
IS DISCONTINUOUS LENSES OF CONGLOMERATE.

NE
E IS VARIABLE. IT OCCURS IN LENSES FREQUENTLY ELONGATED WITH THE
LL STRIKE. SERPENTINE MAY BE SHEARED ALONG FAULT CONTACTS, OR MAY
LE SHEARED BUT FRACTURED INTO IRREGULAR BLOCKS.

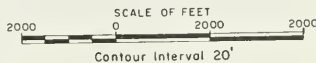
E GROUP
AINEO, POORLY SORTED, GRAY SANDSTONE WITH THICK SECTIONS OF NODULAR
D GREENISH GRAY CLAY SHALE. CONTAINS NODULES AND THIN BEDS OF GRAY
ONE. POORLY SORTED PEBBLE CONGLOMERATE IS ALSO PRESENT.

OS.

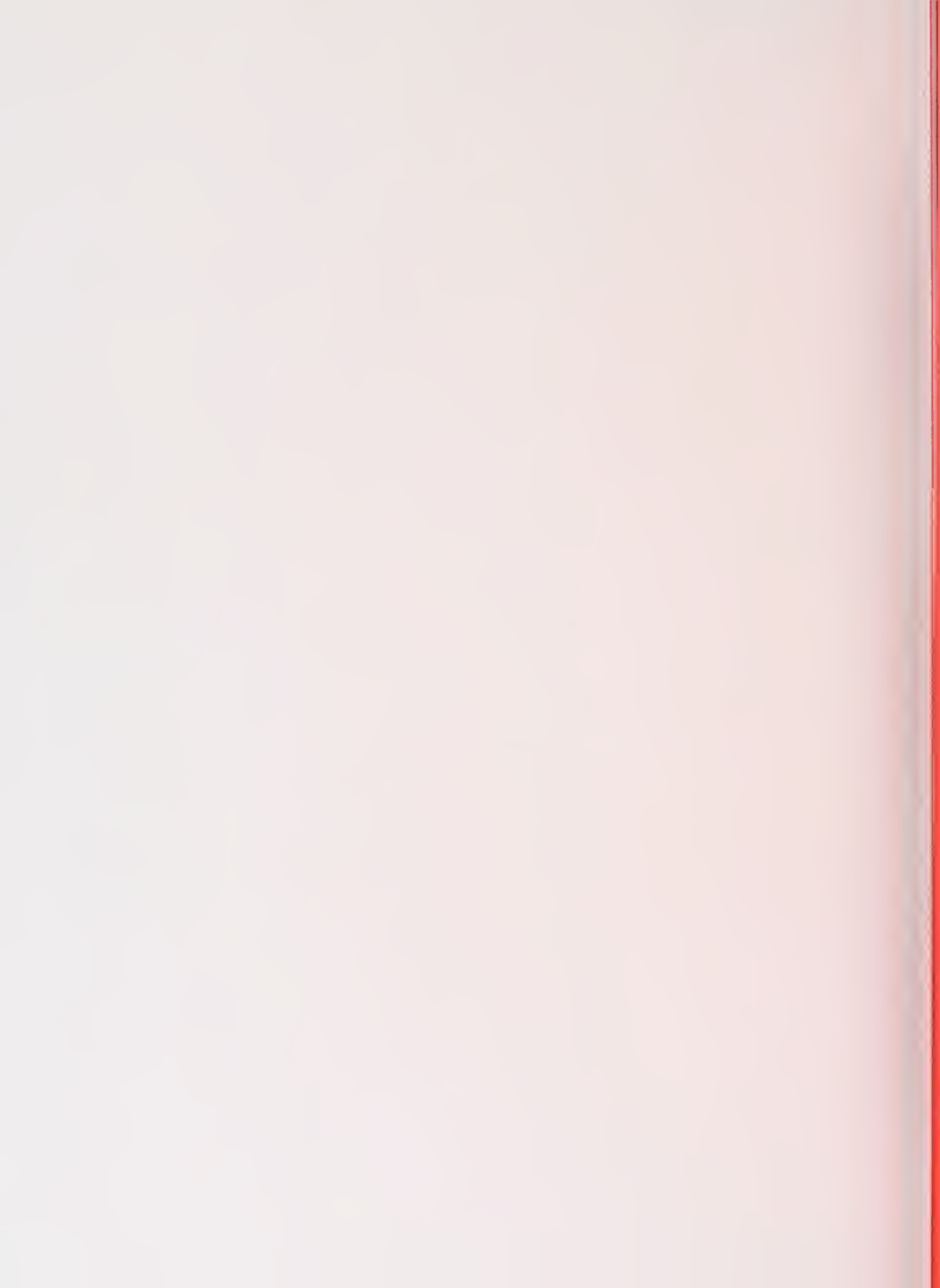
ERE APPROXIMATELY LOCATED)

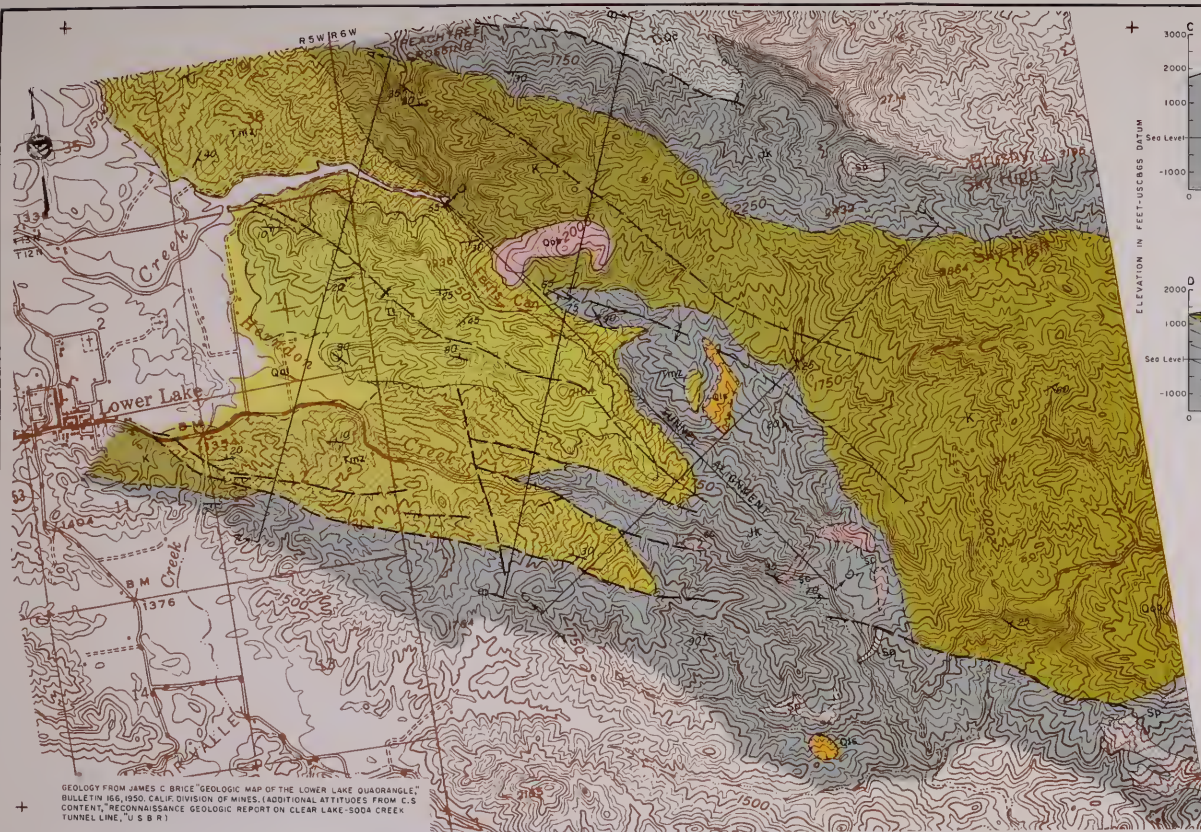
E APPROXIMATELY LOCATED)

STATE OF CALIFORNIA
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GEOLOGIC MAP AND SECTIONS
SODA CREEK TUNNEL



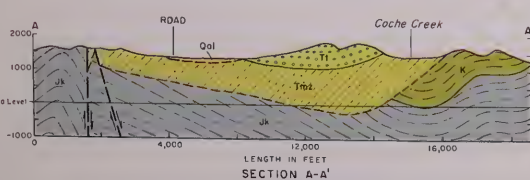
RICE "STRUCTURE SECTIONS
E" PLATE 7 OF CALIFORNIA
S.



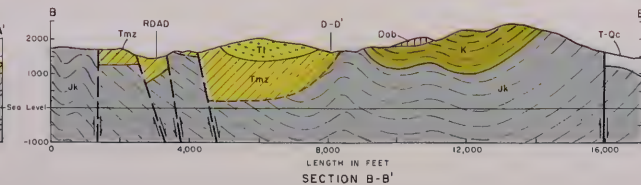


GEOLOGY FROM JAMES C. BRICE, "GEOLOGIC MAP OF THE LOWER LAKE QUADRANGLE," BULLETIN 166, 1950, CALIF. DIVISION OF MINES. (ADDITIONAL ATTITUDES FROM C.S. CONTENT), RECONNAISSANCE GEOLOGIC REPORT ON CLEAR LAKE-SODA CREEK TUNNEL LINE, U.S.G.M.R.1

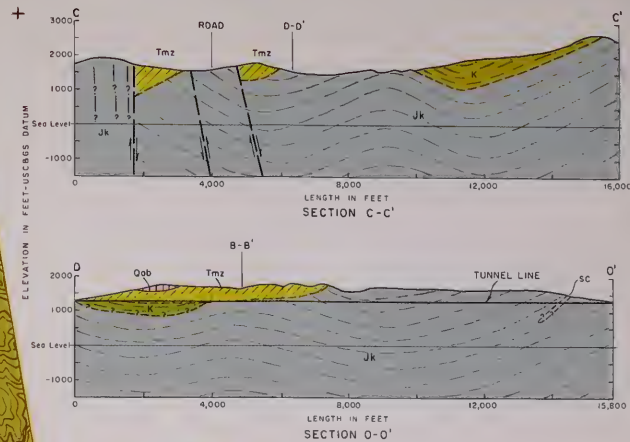
ELEVATION IN FEET-USCARB DATUM



SECTION A-A'



SECTION B-B'



SECTION C-C'

SECTION D-D'

- LEGEND**
- RECENT**
 - Qls** LANDSLIDES (SERPENTINE OR LAVA USUALLY INVOLVED).
 - Qol** ALLUVIUM, CLAY, SAND, GRAVEL.
 - Qob** OLIVINE BASALT. MEDIUM TO LIGHT GRAY, PORPHYRITIC OLIVINE BASALT. PHENOCRYSTS ARE OLIVINE AND PYROXENE. QUARTZ INCLUSIONS ARE COMMON.
 - T-Oc** CACHE FORMATION. LIGHT GRAY SILT INTERBEDDED WITH GRAVEL AND SAND. TUFFS, TUFFACEOUS SANDS, PEBBLY LIMESTONE AND DIATOMITE OCCUR NEAR THE TOP OF THE SECTION.
 - SC** SILICACARBONATE ROCK. SILICA MINERALS, FREQUENTLY OPAL, ASSOCIATED WITH CARBONATES OF THE CALCITE GROUP. MAY HAVE A VEINED OR SCHISTOSE STRUCTURE. IT IS COMMONLY FOUND IN ELONGATED MASSES IN FAULT ZONES AND NEAR SERPENTINE.
 - TEJON FORMATION**
 - T1** WHITE CONGLOMERATIC SANDSTONE. THE CONGLOMERATE OCCURS AS BEES, LENSES OR STRINGS OF GENERALLY UNSORTED GRAVELS, PEBBLES OR COBBLES. QUARTZ, CHERT AND VOLCANIC COBBLES PREDOMINATE.
 - Tmz** MARTINEZ FORMATION. SILTY AND CLAYEY SHALE, CONGLOMERATE AND WHITE AND YELLOW SANDSTONE. THE CONGLOMERATE CONTAINS POORLY SORTED PEBBLES OF CHERT, QUARTZ, AND IGNEOUS ROCK.
 - K** CRETACEOUS ROCKS (UNDIFFERENTIATED). SANDSTONE AND SHALE IN APPROXIMATELY EQUAL PROPORTIONS. THE SANDSTONE IS MASSIVE, YELLOWISH BROWN, AND FINE TO MEDIUM GRAINED. IT IS POORLY SORTED AND CONTAINS DISCONTINUOUS LENSES OF CONGLOMERATE.
 - Sp** SERPENTINE. TEXTURE IS VARIABLE. IT OCCURS IN LENSES FREQUENTLY ELONGATED WITH THE REGIONAL STRIKE. SERPENTINE MAY BE SHEARED ALONG FAULT CONTACTS, OR MAY BE LITTLE SHEARED BUT FRACTURED INTO IRREGULAR BLOCKS.
 - JK** KNOXVILLE GROUP. FINE GRAINED, POORLY SORTED, GRAY SANDSTONE WITH THICK SECTIONS OF NODULAR GRAY TO GREENISH GRAY CLAY SHALE. CONTAINS NODULES AND THIN BEDS OF GRAY LIMESTONE. POORLY SORTED PEBBLE CONGLOMERATE IS ALSO PRESENT.

- STRIKE AND DIP OF BEES.**
- VERTICAL BEES.**
- CONTACT (DASHED WHERE APPROXIMATELY LOCATED)**
- FAULT (DASHED WHERE APPROXIMATELY LOCATED)**
- PROBABLE SYNCLINE**
- PROBABLE ANTICLINE**
- GEOLOGIC SECTION LINE**

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**GEOLOGIC MAP AND SECTIONS
SODA CREEK TUNNEL**
SCALE OF FEET
2000 0 2000
Contour interval 20'

SECTION A-A' B-B' ARE FROM BRICE "STRUCTURE SECTIONS ACROSS LOWER LAKE QUADRANGLE" PLATE 7 OF CALIFORNIA DIVISION OF MINES BULLETIN 166.





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